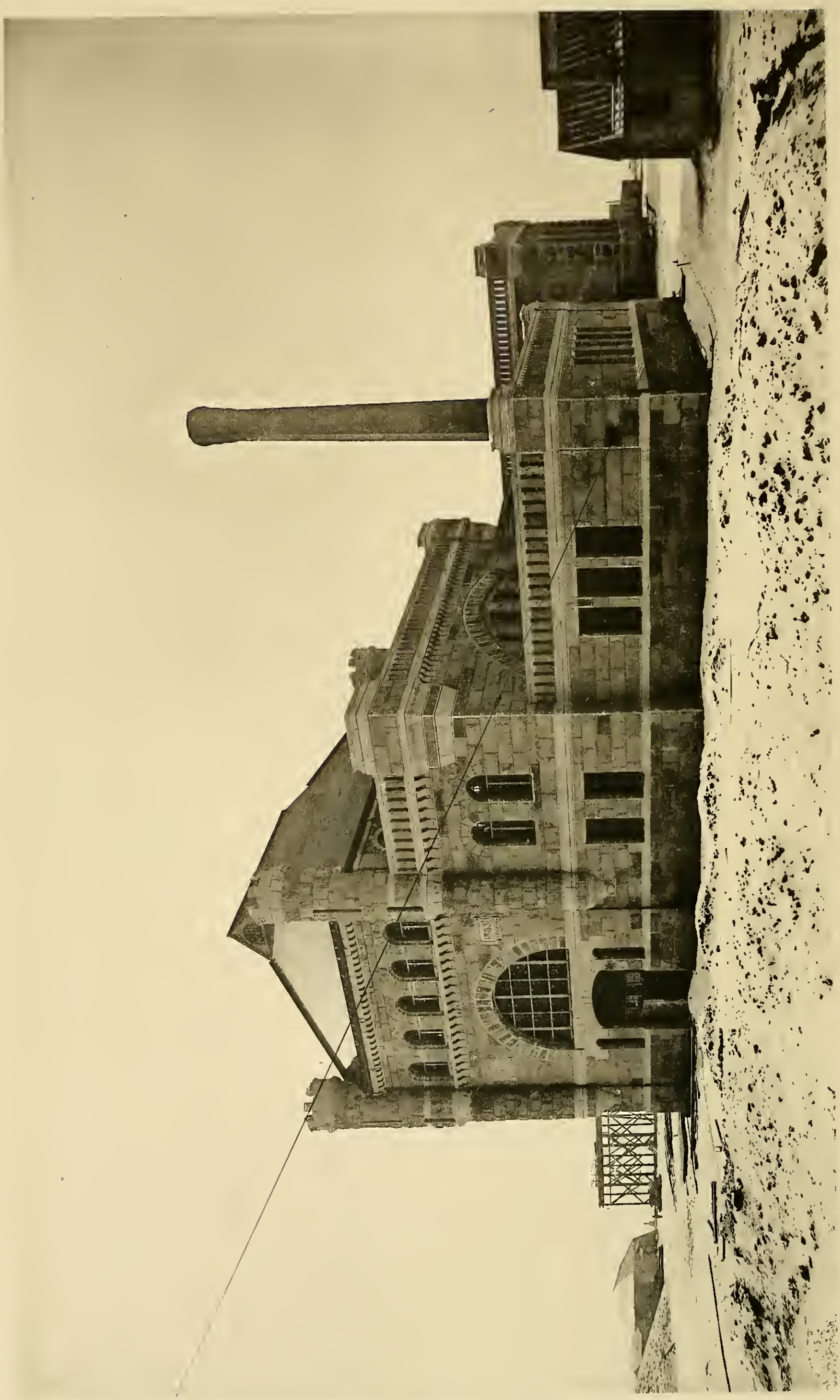
SICUT PATRIBUS SIT DEUS NOBIS
BOSTONIA
CONDITA A.D. 1630.
CIVITATIS REGIMINE DONATA A.D. 1822.

Plate XVI.



Main Drainage Pumping Station. Front View.

HELIOTYPE PRINTING CO., BOSTON

MAIN DRAINAGE WORKS

OF THE

CITY OF BOSTON

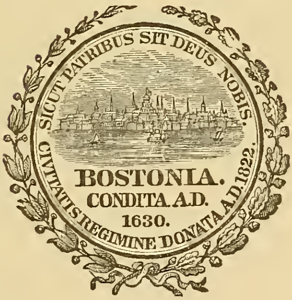
(*MASSACHUSETTS, U.S.A.*)

BY

ELIOT C. CLARKE

PRINCIPAL ASSISTANT ENGINEER, IN CHARGE

THIRD EDITION



BOSTON
ROCKWELL AND CHURCHILL, CITY PRINTERS
No. 39 ARCH STREET
1888

CITY OF BOSTON.

In Board of Aldermen, May 11, 1885.

Ordered, That the Committee on Improved Sewerage prepare and have printed a history of the works under their charge, at an expense not exceeding $1,500, to be charged to the appropriation for Improved Sewerage.

Passed in Common Council. Came up for concurrence. Concurred. Approved by the Mayor, May 13, 1885.

A true copy.

Attest: JOHN T. PRIEST,
Ass't City Clerk.

In Board of Aldermen, Sept. 14, 1885.

Ordered, That the Clerk of Committees be authorized to prepare and print one thousand additional copies of the "Report on Main Drainage," with an appendix giving a digest of the action of the City Council in originating and prosecuting the work upon the system of Improved Sewerage; the expense thus incurred to be charged to the appropriation for Improved Sewerage.

Passed. Sent down for concurrence. September 18, came up concurred. Approved by the Mayor, September 22, 1885.

A true copy.

Attest: JOHN T. PRIEST,
Ass't City Clerk.

In Board of Aldermen, Oct. 12, 1885.

Ordered, That the Clerk of Committees be authorized to have two hundred copies of the "Report on Main Drainage" printed, in addition to the number he is already authorized to print, by an order passed September 22, 1885; and the City Messenger is hereby authorized to place said copies on sale in his office at the price of one dollar and twenty-five cents each, the proceeds of such sale to be credited to the appropriation for Improved Sewerage.

Passed. Sent down for concurrence. October 15, came up concurred. Approved by the Mayor, October 19, 1885.

A true copy.

Attest: JOHN T. PRIEST,
Ass't City Clerk.

In Board of Aldermen, Dec. 27, 1887.

Ordered, That the Clerk of Committees be authorized to have an additional fifteen hundred copies of the "Report on Main Drainage Works" printed; the expense thus incurred to be charged to the appropriation for Improved Sewerage, and that ten copies be given to each member of this government.

Passed. Sent down for concurrence.

In Common Council, Dec. 29, 1877.

Concurred.

Approved by the Mayor, December 31, 1887.

A true copy.

Attest: JOHN T. PRIEST,
Ass't City Clerk.

PREFACE TO THIRD EDITION.

THE desirability of reprinting the "History of the Main Drainage Works" became manifest on account of the unabated demand for the book among engineers and scientific men both in this country and abroad. The City Engineer, in his request to the City Council for another edition of the book, says: —

"There is a constant demand for copies of this book, both from citizens and from others, the work having, in addition to its interest as a description of an important local improvement, a great value to the engineering profession and to municipalities contemplating similar improvements."

The only changes to be found in the new reprint are in the Appendices; the financial statement being continued to the present date, and additions being made in the list of officials and committees of the City Council connected with the work.

J. L. H.

CITY HALL, Boston, 1887.

PREFACE TO SECOND EDITION.

THE second edition of this work was ordered by the City Council to meet the pressing calls for copies which were continually being received. This edition is an exact reprint of the first, with the addition, in Appendix B, of a review of the action of the City Council in regard to the origin and progress of the work. The disconnected character of the review will be accounted for, when it is understood that the Committee on Improved Sewerage, appointed each year, had practically the entire charge of the work, and exercised full executive powers in regard to contracts, general construction, and the employment of labor; while the City Council was merely called upon to act in regard to matters that required legislation, the settlement of claims, the taking of lands, and general questions in regard to the methods of carrying on the work. The extensive powers of the Committee were set aside by the law amending the City Charter, Acts of 1885, Chap. 266, which went into effect June 26, 1885.

J. L. H.

CITY HALL, Boston, 1885.

PREFACE TO FIRST EDITION.

THIS brief description of the Main Drainage Works, of Boston, aims to record, for the benefit of engineers, an account of the engineering problems involved and the methods of construction adopted. It also aims to give to the tax-payers and general public a descriptive account of why the large appropriation for "An Improved System of Sewerage" was needed, and how it has been spent. By attempting to accomplish both of these purposes it fulfils neither of them adequately; since one class of readers will find it too technical, and the other too deficient in detail. It has been prepared amid pressing engagements, and to save time the writer has not hesitated to borrow freely from previous reports, by himself and others. Traces of such compilation will, doubtless, be noticed by the discerning. It is hoped that a fair idea of the works can be obtained from the illustrations; and that the description, even by its defects, may encourage other engineers to publish, as they too seldom do, accounts of works with which they have been connected.

E. C. C.

CITY HALL, Boston, April, 1885.

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MAIN DRAINAGE WORKS.

CHAPTER I.

EARLY HISTORY OF SEWERAGE AT BOSTON.

The conditions which necessitated a change in the system of sewage disposal at Boston, and the problems to be solved in making that change, can be better understood after a brief consideration of the early history of sewerage at that city and the manner in which the sewers were originally built.

Boston was first settled in 1630. When the first sewer was built cannot now be determined, but it was earlier than the year 1700, for already, in 1701, the population being about 8,000, a nuisance had been created by frequent digging up of streets to lay new sewers and to repair those previously built; and in town meeting, September 22, 1701, it was ordered, "That no person shall henceforth dig up the Ground in any of the Streets, Lanes or High-ways in this Town, for the laying or repairing any Drain, without the leave or approbation of two or more of the Selectmen."

The way in which sewers were built at this time was, apparently, this. When some energetic householder on any street decided that a sewer was needed there, he persuaded such of his neighbors as he could to join him in building a street drain. Having obtained permission to open the street, or perhaps neglected this preliminary, they built such a structure as they thought necessary, on the shortest line to tide-water. The expense was divided between them, and they owned the drain absolutely. Should any new-comer, or any neighbor, who had at first declined to assist in the undertaking, subsequently desire to make use of the drain, he was made to pay for the privilege what the proprietors saw fit to charge. When a drain needed repairing all persons using it were expected to pay their share of the cost.

As might have been expected, under such a system, great difficulty was experienced in distributing fairly the expenses and in collecting the sums due; so that it became of sufficient importance to engage the attention of the Legislature, and in 1709 an act was passed regulating these matters. It is entitled, "An Act — Passed by the Great and General Court or Assembly of her Majesty's[1] Province of the Massachusetts-Bay. For regulating of Drains and Common Shores.[2] For preventing of Inconveniences and Dammages by frequent breaking up of High-Wayes . . . . and of Differences arising among Partners in such Drains or common Shores about their Proportion of the Charge for making and repairing the same."

The act recites that no person may presume to break up the ground in any highway within any town for laying, repairing, or amending any common shore, without the approbation of the selectmen, on pain of forfeiting 20 shillings to the use of the poor of said town; that all such structures, for the draining of cellars, shall be "substantially done with brick or stock;"[3] that it shall be lawful for any inhabitant of any town to lay a common shore or main drain, for the benefit of themselves and others who shall think fit to join therein, and every person who shall afterwards enter his or her particular drain into such main drain, or by any more remote means receives benefits thereby, for the drainage of their cellars or lands, shall be obliged to pay unto the owner or owners a proportionate part of the charge of making or repairing the same, or of that part of it below where their particular drain enters. In case of dispute the selectmen decided how much each person should pay, and there was an appeal from their decision to the courts.

For one hundred and fifteen years the sewers in Boston were built, repaired, and owned by private individuals under authority of this act.

It may be doubted if most of them were "substantially done with brick or stock," and there certainly was much difficulty

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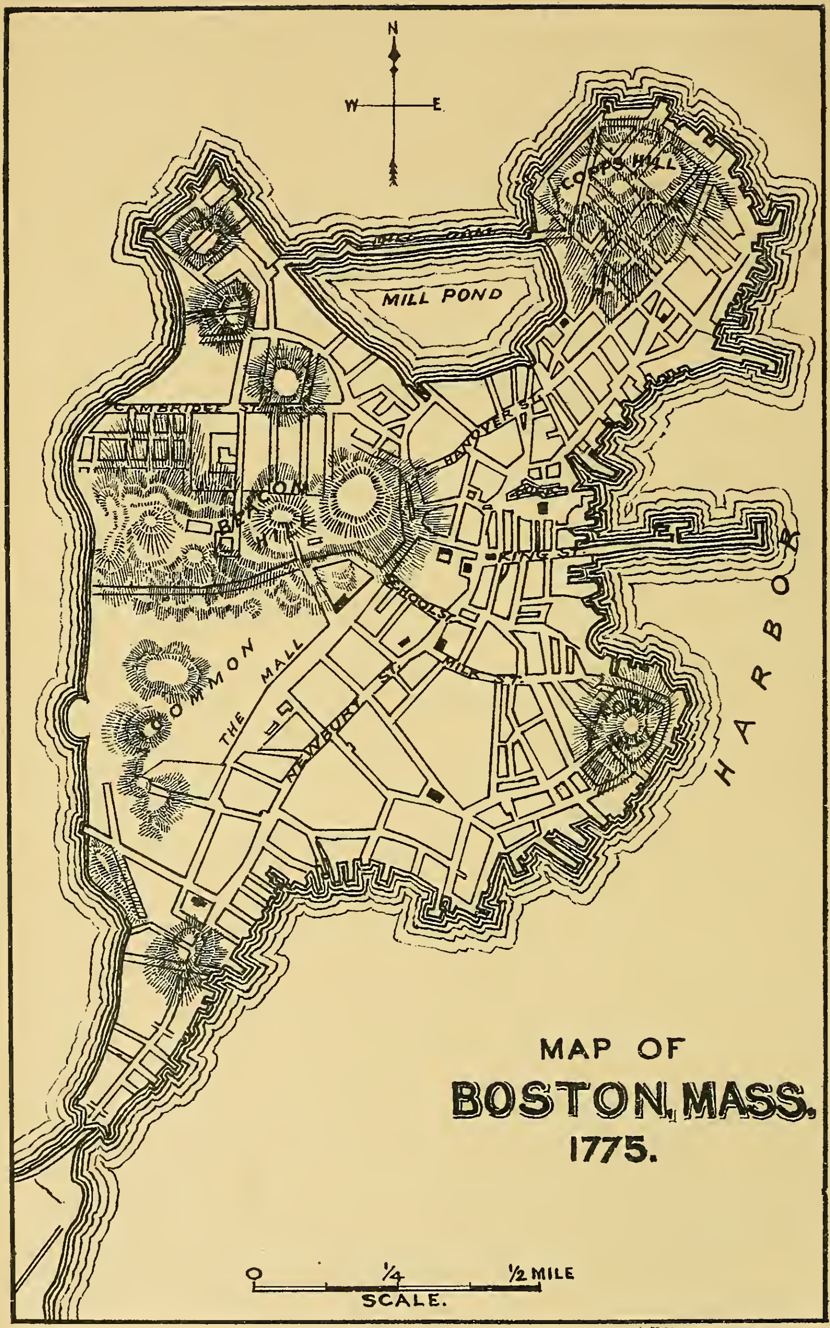
[1] Anne. [2] Sewers. [3] Stone.

PLATE I.



Heliotype Printing Co. Boston.

about payments; so that in 1763 the act of 1709 was amended, the amendment reciting that "Whereas it frequently happens that the main drains and common shores decay or fill up . . . . and no particular provision is made by said act to compell such persons as dwell below that part where said common shores are repaired, and have not sustained damage, to pay their proportionable share thereof, as shall be adjudged by the selectmen, which has already occasioned many disputes and controversies," therefore it was decreed that in future all persons benefited should pay for repairs.

No further change was made till 1796, and then only to provide that persons who did not pay within ten days of notification should pay double, and that the sewers, besides being of brick or stone, might be built of such other material (probably wood) as should be approved by the selectmen.

Under this act the greater part of Boston was sewered by private enterprise. The object for which the sewers were built was, as indicated, "for the draining of cellars and lands." The contents of privy-vaults, of which every house had one, and even the leakage from them, were excluded; but they received the waste from pumps and kitchen-sinks, and also rain-water from roofs and yards.

That much refuse got into them is proved by their frequently being filled up, and as they had a very insufficient supply of water they were evidently sewers of deposit. That they served their purpose at all is due to the fact that the old town drained by them, as shown in Plate I., consisted of hills with good slopes on all sides to the water. Of this early method of building sewers Josiah Quincy, then Mayor, said, in 1824: "No system could be more inconvenient to the public, or embarrassing to private persons. The streets were opened with little care, the drains built according to the opinion of private interest or economy, and constant and interminable vexatious occasions of dispute occurred between the owners of the drain and those who entered it, as to the degree of benefit and proportion of contribution."

In 1823 Boston obtained a city charter, and one of the first acts of the city government was to assume control of all existing sewers and of the building and care of new ones. The new sewers were built under the old legislative acts, and the whole expense, as before, was charged to the estates benefited, being divided with reference to their assessed valuation. A small, variable portion of the cost was, however, generally assumed by the city, in consideration of the use of the sewers for removing surplus rain-water from the public streets.

The city ordinances regulating sewers required that, when practicable, they should be of sufficient size to be entered for cleaning. Some supervision was exercised over connecting house-drains, and, if thought necessary, a strainer could be placed on each. Fecal matters were rigidly excluded until 1833, when it was ordered that, while there must be no such connection between privy-vaults and drains as would pass solids, the Mayor and Aldermen, at their discretion, might permit such a passage or connection as would admit fluids to the drain. This action was perhaps due to an advent of cholera during the previous year. To assist in flushing out deposits, it was provided, in 1834, that any person might discharge rain-water from his roof into the sewers, without any charge for a permit. The same year control of the sewers and sewer-assessments was given to the City Marshal. He was especially to devote himself to the collection of assessments, new and old, which were largely unpaid. The other duties of the marshal probably prevented him from devoting sufficient energy to the accomplishment of this task; for it appears that, while there had been expended by the city, for building sewers, from 1823 to 1837, the sum of $121,109.52, there had been collected of this sum but $26,431.31.

That there might be some one to give his whole time to the financial and administrative duties connected with the sewerage system, a "Superintendent of Sewers and Drains" was appointed in July, 1837. He was empowered to assess the whole cost of any new sewer upon the real estate, including buildings benefited by it. In 1838 the city decided to assume one-quarter of the gross cost, and in 1840, in obedience to a decision by the Supreme Court, it was ordered that the three-quarters of the cost of sewers which was to be paid by the abutters should be assessed with reference to the value of the land only, without taking into consideration the value of buildings or other improvements, and such has been the practice up to the present time.

It is estimated that there are at the present time (1885) about 226 miles of sewers in Boston. In 1873 there were about 125 miles, and in 1869 about 100 miles. There are at present supposed to be more than 100,000 water-closets in use in the city; in 1857 there were 6,500.

CHAPTER II.

CHARACTER AND DEFECTS OF THE OLD SEWERAGE SYSTEM.

Such changes have taken place in the contours of the city, through operations for reclaiming and filling tidal areas bordering the old limits, that from being a site easy to sewer, Boston became one presenting many obstacles to the construction of an efficient sewerage system.

This will be understood from an examination of the plan of the city proper, Plate V. On this plan the shaded portion represents the original area of the city, and very nearly its limits in 1823. The unshaded portion of the plan, indicating present limits, consists entirely of reclaimed land filled to level planes little above mean high water, the streets traversing such districts being seldom more than seven feet above that elevation. A large proportion of the house basements and cellars in these regions are lower than high water, and many of them are but from five to seven feet above low-water mark, the mean rise and fall of the tide being ten feet. This lowness of land surface and of house cellars necessitates the placing of house-drains and sewers at still lower elevations. Most house-drains are under the cellar floors, and fall in reaching the street sewers; the latter must be still lower, and in their turn fall towards their outlets, which were rarely much, if at all, above low water.

Moreover, as filling progressed on the borders of the city, it became necessary to extend the old sewers whose outlets would have been cut off. The old outlets being generally at a low elevation, even where the sewers themselves were sufficiently high, the extensions had to be built still lower, and when of considerable length could have but little fall towards the new mouths.

As a consequence, the contents of the sewers were dammed back by the tide during the greater part of each twelve hours.

To prevent the salt water flowing into them many of them were provided with tide-gates, which closed as the sea rose, and excluded it. These tide-gates also shut in the sewage, which accumulated behind them along the whole length of the sewer, as in a cesspool; and, there being no current, deposits occurred. The sewers were, in general, inadequately ventilated, and the rise of sewage in them compressed the foul air which they contained, and tended to force it into the house connections. To afford storage room for the accumulated sewage many of the sewers were built very much larger than would otherwise have been necessary, or than was conducive to a proper flow of the sewage; and, as there would have been little advantage in curved inverts where there was to be no current, flat-bottomed and rectangular shapes were frequently adopted.

Although at about the time of low water the tide-gates opened and the sewage escaped, the latter almost immediately met the incoming tide, and was brought back by it to form deposits upon the flats and shores about the city. Of the large amount of sewage which flowed into Stony Brook and the Back Bay, and especially that which went into South Bay, between Boston proper and South Boston, hardly any was carried away from the vicinity of a dense population.

The position of the principal sewer outlets, and of the areas on which the sewage which caused most offence used to accumulate, is indicated on Plate V. From these places foul-smelling gases and vapors emanated, which were diffused to a greater or less distance, according to the state of the temperature or of the atmosphere. Under certain conditions of the atmosphere, especially on summer evenings, a well-defined sewage odor would extend over the whole South and West Ends of the city proper.

This evil was thus described by the City Board of Health in one of their annual reports: —

> Complaints of bad odors have been made more frequently during the past year than ever before.
>
> They have come from nearly all parts of the city, but especially and seriously from the South and West Ends.

Large territories have been at once, and frequently, enveloped in an atmosphere of stench so strong as to arouse the sleeping, terrify the weak, and nauseate and exasperate everybody.

It has been noticed more in the evening and by night than during the day; although there is no time in the whole day when it may not come.

It visits the rich and the poor alike. It fills the sick-chamber and the office. Distance seems to lend but little protection. It travels in a belt half-way across the city, and at that distance seems to have lost none of its potency, and, although its source is miles away, you feel sure it is directly at your feet. . . . .

The sewers and sewage flats in and about the city furnish nine-tenths of all the stenches complained of.

They are much worse each succeeding year; they will be much worse next year than this.

The accummulation of sewage upon the flats and about the city has been, and is, rapidly increasing, until there is not probably a foot of mud in the river, in the basins, in the docks, or elsewhere in close proximity to the city, that is not fouled with sewage.

Various palliative measures were adopted. The Back Bay, into which the waters of Stony Brook, and with them most of the sewage of Roxbury and Jamaica Plain, used to empty, was lately partly filled with gravel, forming the present Back-Bay Park. The brook was carried in a covered channel to Charles River, which somewhat lessened the nuisance caused by it, or at least transferred it to another locality. Owing to complaints from the physicians of the City Hospital and other residents in that neighborhood, the city purchased and filled the upper portion of Old Roxbury Canal at the head of South Bay. The sewers emptying into it were extended, and the position of the nuisance caused by them was thus altered by a few hundred feet. In general terms, it may be said that none of the old sewer outlets were in unobjectionable locations.

There are no plans in detail of the sewers of Boston. Many of the older ones have no man-holes. In some streets several sewers exist side by side. Occasionally a sewer is found built directly above an older one. Probably one-half of the larger main sewers are wholly or partly built of wood, and have flat bottoms. An unwise provision was inserted in the charters of some of the private corporations organized for the purpose of reclaiming and filling areas of flats, by which it was stipulated

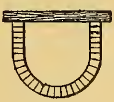


Fig. 1

Fig. 2

Fig. 3

Fig. 4

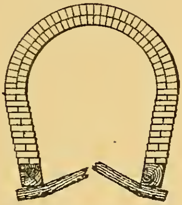


Fig. 9

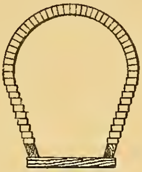


Fig. 10

Fig. 11

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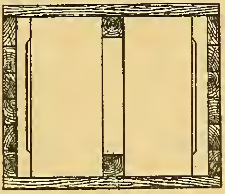

Fig. 15

HOL

Fig. 23

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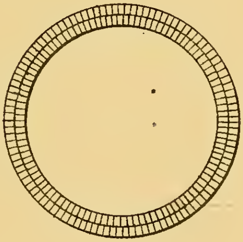


Fig. 17

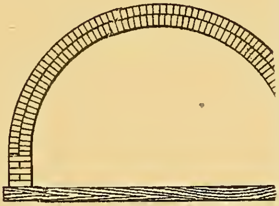


Fig. 18

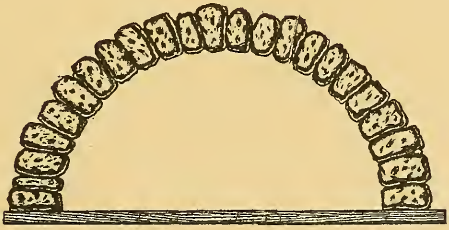
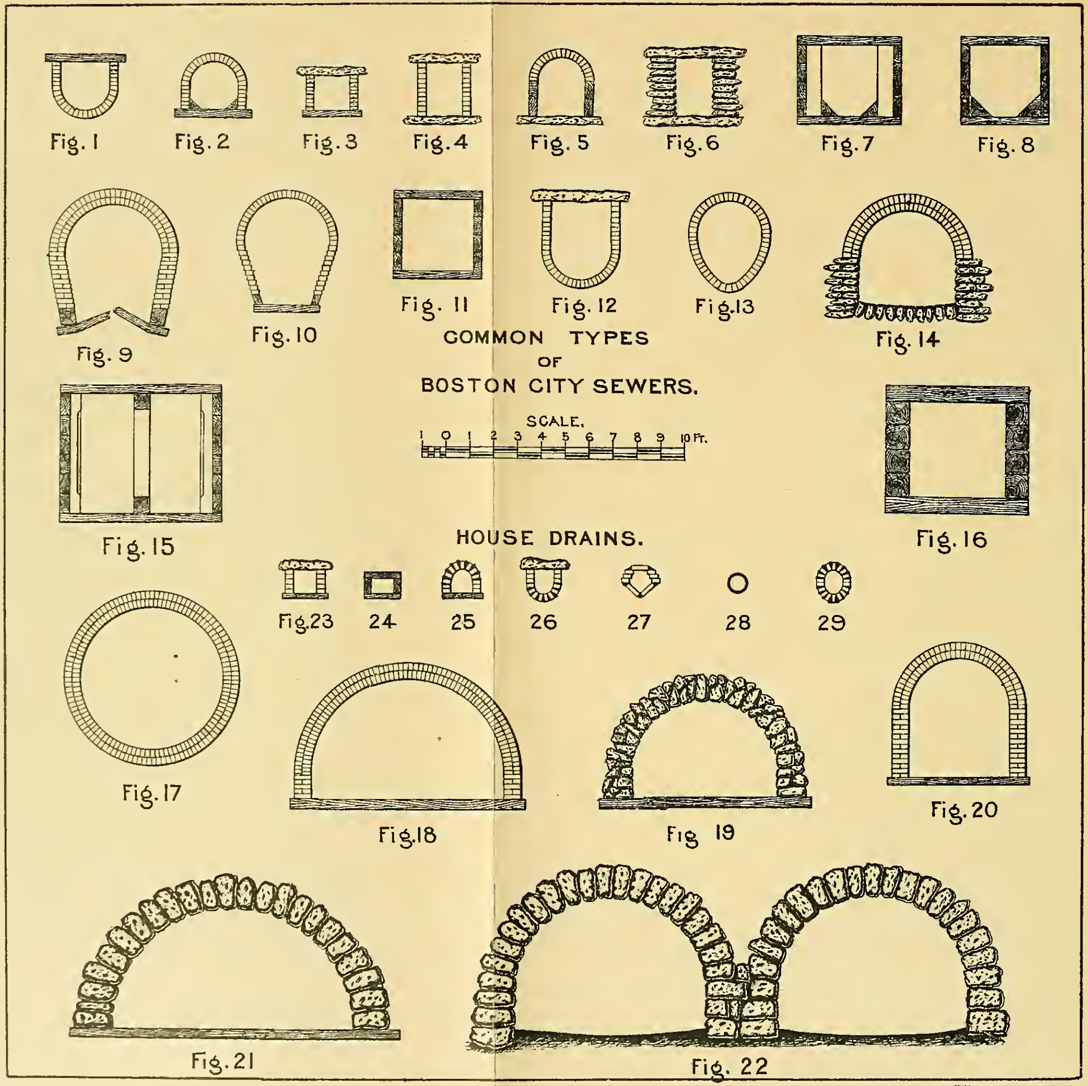


Fig. 21

PLATE II.



Heliotype Printing Co Boston.

that the corporations should themselves extend all sewers whose discharge would be obstructed by the filling. Such extensions were made without system, by building flat-bottomed wooden scow sewers, which were laid upon the soft surface of the flats before the filling was done. Cross-sections of various common forms of existing city sewers are shown on Plate II., Figs. 1 to 22. Fig. 22 shows Stony-Brook culvert, which constitutes the lower mile of Stony Brook and is that part of it which is covered and used as a sewer.

One fact which increased the danger arising from the damming up of the sewers, and the consequent compression of their gaseous contents, was that the house-drains connecting with these sewers were ill adapted to resisting this pressure. Most of them were built of brick or of wood, before the rise of modern ideas in regard to sanitary drainage; and, as they were usually leaky, the gases forced into them found ready egress into the houses. Figs. 23 to 29 on Plate II. show common forms of these house-drains.

The drains differ greatly in size. Of 113 which were observed while building the intercepting sewers in 1878, —

11	were about	4	inches	in diameter.	
4	"	5	"	"	
21	"	6	"	"	
5	"	7	"	"	
27	"	8	"	"	
8	"	9	"	"	
11	"	10	"	"	
26	"	12	"	"	or more.
113					

Of these 113 drains, 9 were level and 14 pitched the wrong way; 45 had flat bottoms and 68 curved ones; 38 were wholly or partly choked with sludge, and 75 were reasonably clean. At about the same time examinations made with peppermint, by the City Board of Health, of 351 house-drains in various sections of the city, showed that 193 of them, or 55 per cent., were defective in regard to tightness.

CHAPTER III.

MOVEMENTS FOR REFORM—COMMISSION OF 1875.

For the ten years preceding 1875 the average annual death-rate of Boston was about 25 in 1,000. On April 14, 1870, the Consulting Physicians of the city addressed to the authorities a remonstrance as to the then existing sanitary condition of the city, in which they declared the urgent necessity of a better system of sewerage, stating that it would be a work of time, of great cost, and requiring the highest engineering skill.

At about the same time, and in each of their annual reports thereafter, the State Board of Health referred to the matter, saying that the question of drainage for Boston and its immediate surroundings was of an importance which there was no danger of overstating.

Of such great importance was the matter considered by the State Legislature that, in the special session of 1872, an act was passed authorizing the appointment of a commission, to be paid by the City of Boston, to investigate and report upon a comprehensive plan for a thorough system of drainage for the metropolitan district. This was not accepted by Boston, on the ground that the expense should be shared by the neighboring cities and towns, and no commission was appointed.

In a communication to the City Council (Dec. 28, 1874), upon the necessity of improved sewerage, the City Board of Health pointed out clearly the evils of the existing system, and strongly urged that a radical change should be made. March 1, 1875, an order passed the City Council authorizing the Mayor to appoint a commission, "consisting of two civil engineers of experience and one competent person skilled in the subject of sanitary science, to report upon the present sewerage of the city . . . . and to present a plan for outlets and main lines of sewers, for the future wants of the city." The Mayor thereupon appointed as members of the commission Messrs. E.

S. Chesbrough, C.E., Moses Lane, C.E., and Charles F. Folsom, M.D., and in December of the same year their report was submitted.

As was to be expected from the professional attainments and reputation of these gentlemen, the report contained a comprehensive and exhaustive statement of the defects in the existing system of sewerage, and of the causes which had produced such a condition of affairs, and finally recommended for adoption a well-considered plan for remedying present defects and for providing for future needs.

The commission stated, as essential conditions of efficient sewerage: first, that the sewage should start from the houses, and flow in a continuous current until it reached its destination, either in deep water or upon the land; and, second, that the sewers should be ventilated so that the atmosphere in them should attain the highest possible degree of purity. To quote from the report: —

The point which *must* be attended to, if we would get increased comforts and luxuries in our houses, without doing so at cost of health and life, is to get our refuse out of the way, far beyond any possibility of harm before it becomes dangerous from putrefaction. In the heat of summer this time should not exceed twelve hours. We fail to do this now in three ways: —

First. We cannot get our refuse always from our house-drains to our sewers, because the latter may not only be full themselves at high tide, but they may even force the sewage up our drains into our houses.

Second. We do not empty our sewers promptly, because the tide or tide-gates prevent it. In such case the sewage being stagnant, a precipitate falls to the bottom, which the slow and gradual emptying of the sewers, as the tide falls, does not produce scour enough to remove. This deposit remains with little change in some places for many months.[1]

Third. With our refuse, which is of an especially foul character, once at the outlets of the sewers, it is again delayed, there to decompose and contaminate the air.

As a result of this failure to carry out the cardinal rule of sewerage, we are obliged to neglect the second rule, which is nearly as important, namely, ventilation of the sewers; for the gases are often so foul that we cannot allow them to escape without causing a nuisance; and we compromise the matter by closing all the vents that we can, with the certainty of poisoning the air of our houses.

[1] The catch-basins, too, in the course of the sewers, serve only to aggravate this evil, and should be filled as early as is practicable.

In the opinion of the commission there are only two ways open to us. The first, raising more than one-half of the superficial area of the city proper (excluding suburbs), is entirely out of the question, from the enormous outlay of money which would be required, — more than four times as much as would be needed for the plan which we propose, and which consists in intercepting sewers and pumping.

There are in use now in various parts of the world three methods of disposing of the sewage of large cities, where the water-carriage system is in use: —

First. Precipitation of the solid parts, with a view to utilizing them as manure, and to purifying the streams.

Second. Irrigation.

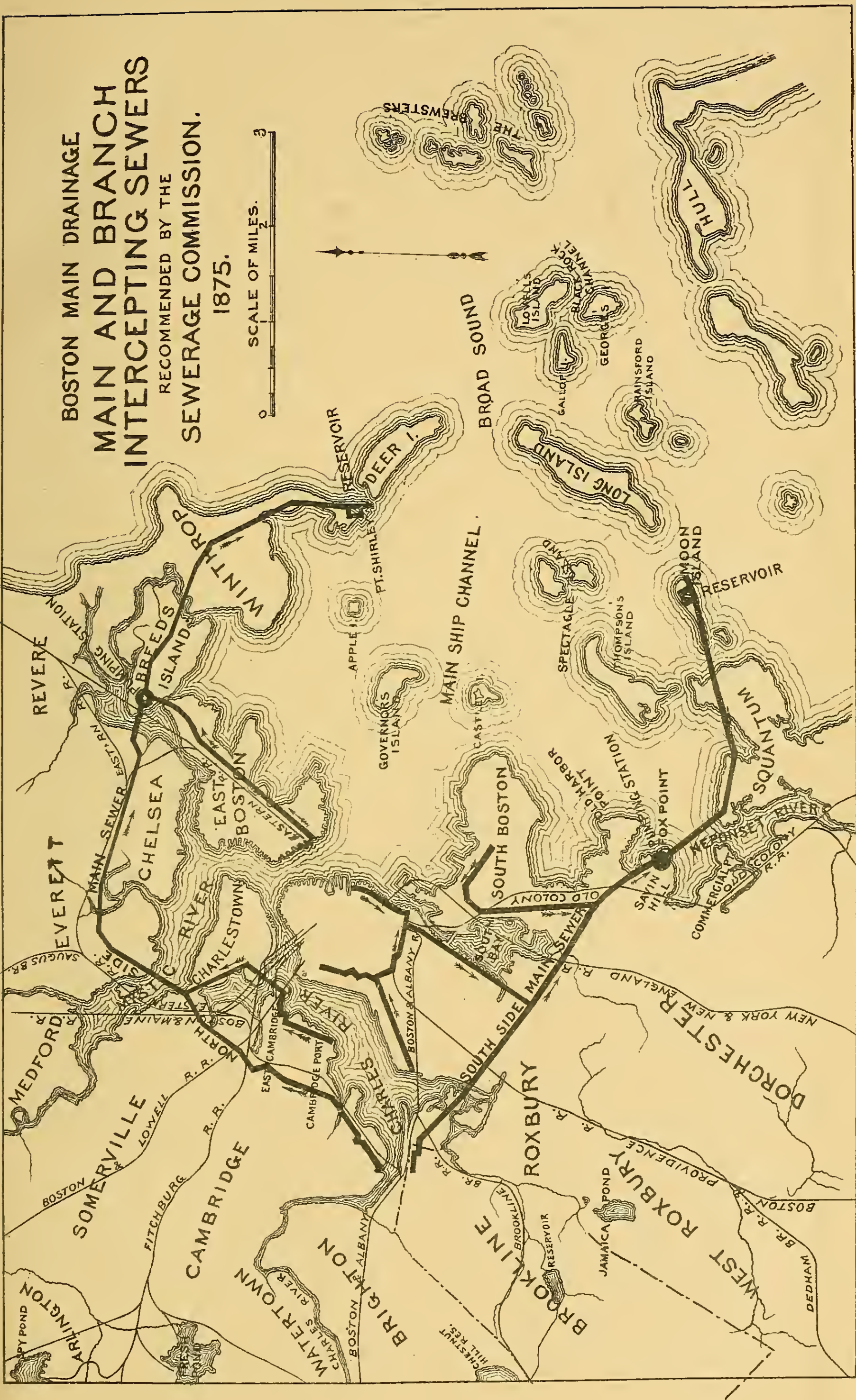
Neither of these processes has proved remunerative, and the former only *clarifies* the sewage *without purifying* it; but if the time comes, when, by the advance in our knowledge of agricultural chemistry, sewage can be profitably used as a fertilizer, or if it should now be deemed best to utilize it, in spite of a pecuniary loss, it is thought that the point to which we propose carrying it will be as suitable as any which can be found near enough to the city, and at the same time far enough away from it.

The third way is that adopted the world over by large cities near deep water, and consists in carrying the sewage out so far that its point of discharge will be remote from dwellings, and beyond the possibility of doing harm. It is the plan which your commission recommend for Boston.

On Plate III. is reproduced a portion of the plan accompanying the report of the commission. The plan shows the routes of the main, intercepting, and outfall sewers recommended, and the proposed locations of the pumping-stations, reservoirs, and outlets. It will be seen that two main drainage systems were proposed, one for each side of the Charles River; that on the south side having its outlet at Moon Island, and that on the north side discharging at Shirley Gut.

The former system was designed to collect and carry off the sewage from all of Boston south of Charles River and from Brookline; the latter was to drain the Charlestown and East Boston districts, and also the neighboring cities of Cambridge, Somerville, and Chelsea. The two systems were identical in their general features. These were: intercepting sewers along the margins of the city to receive the flow from the already existing sewers; main sewers into which the former were to empty and by which the sewage was to be conducted to pumping-stations; pumping machinery to raise the sewage about 35

PLATE III.



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feet; outfall sewers leading from the pumping-stations to reservoirs near the points of discharge at the sea-coast, from which reservoirs the sewage, accumulated during the latter part of ebb and the whole of flood tide, was to be let out into the harbor during the first two hours of ebb-tide.

The cost of the proposed main drainage works, as estimated by the commission in its report, was: —

For the territory south of Charles River . . .	$3,746,500
" north " . . .	2,804,564
Total	$6,551,064

The commissioners' recommendation met with very general acceptance. But, as was to be expected, a certain amount of opposition to it was encountered.

One remonstrance against the adoption of the proposed plan, which was presented to the City Council by a number of estimable citizens, may be of sufficient interest to cite, because it is a type of the kind of objections which are often urged against plans for municipal improvement, however carefully considered by the most competent experts: —

The undersigned respectfully remonstrate against the adoption of the system of sewerage proposed in Report No. 3 of this year. We believe if carried into execution it will prove not only ineffectual, but destructive to the health and prosperity of the city. . . . . . Of late years the cost of many, if not most, of the public works has greatly exceeded the estimates; in some instances, it is said, two or three hundred per cent.

Should this new system exceed the estimates *to a like extent*, the amount would be augmented to between fifteen and twenty millions of dollars. . .

But we do not believe it (flushing) will, or even can, be made to perform that end in an effective or satisfactory manner; because we understand, by the report, that the inclinations of the sewers will afford a flow at a minimum rate of only two miles an hour, so that it will be almost impossible to prevent the glutinous slime and putrefactions from constantly gathering and adhering more or less to the sides and bottoms of the sewers and drains, and as constantly exhaling the deadly gases on every side. . . . . It will likewise be borne in mind that the thick mass of liquid corruption within the sewers and drains must be drawn along to their uphill or final ascent of thirty feet and over, and kept in motion and delivered at the distant outlets on the bay, by means of enormous pumps and machinery worked by steam-engines, ... for a stoppage in the operations of such an extensive system for only a day or two, along the low lands and other parts of the city, would almost inevitably result in serious maladies and other evil consequences. . . . . Will not the exhalation and odor (from the storage reservoirs) blown by every changing wind here and there along the wharves, upon the shipping and back upon the land, create a nuisance so offensive and unhealthful as to become intolerable? No provision seems to be devised to prevent such emanations or their baleful consequences. In these noisome reservoirs the contents must ever be exposed to the sun, the storms, and the inclemency of the weather.

In the severity of winter they must become as frozen as the water in the bay or along the shores; and as often as they are converted into ice there must be an entire stoppage of the works. . . . Such reservoirs and outlets might be reduced to ruins in any future day of hostilities — either foreign or domestic — should such hostilities ever occur, the effect of which ruins would be the fatalities of the plague. . . . .

There is now but a single system before the authorities, although there are not less than five different systems in Europe alone. . . . It is hereby requested that the same be postponed, and that a reward be offered for the best plan for sewerage relief . . . . and that such plans be referred to a commission of citizens . . . . with power to give the reward for the best plan.

Other remonstrants thought that city sewage had a great manurial value, and should be so utilized as to be a source of revenue; still others considered the proposed scheme extravagant, and advised temporary palliative measures.

What prevented these remonstrances from having much weight was that, while criticising the proposed scheme, they either suggested no alternative plan, or else failed to show that the method which they themselves recommended would remedy the existing evils.

As a compromise the City Council inclined to adopt the recommendations of the commission in so far as they referred to the territory south of Charles River, which included those portions of the city which suffered most from ineffective sewerage. Application was made to the Legislature for authority to construct works in general accordance with the recommendations of the commissioners, and an act, approved April 11, 1876, entitled "An Act to empower the City of Boston to lay and maintain a main sewer discharging at Moon Island in Boston Harbor, and for other purposes," was passed.

The subject had been referred by the City Council to a Joint

Special Committee on Improved Sewerage, and in June, 1876, this committee reported, recommending the adoption of the system devised by the commission, and that surveys and estimates be made for the work, and also that the feasibility of an outlet at Castle Island be considered.

By an order approved July 17, 1876, the sum of $40,000 was appropriated for the purpose of making surveys and of procuring estimates for an improved system of sewerage for the City of Boston, on a line from Tremont Street to Moon Island, and also on a line from said street to deep water east of Castle Island.

A few days later the City Engineer, Mr. Joseph P. Davis, appointed the writer principal assistant, in immediate charge of the survey and investigations, which were at once begun.

CHAPTER IV.

PRELIMINARY INVESTIGATIONS.

By a liberal interpretation of the order in compliance with which the survey was carried on, it was assumed that any information was desired which might be of use in designing main drainage works, in general accordance with the plan recommended by the commission.

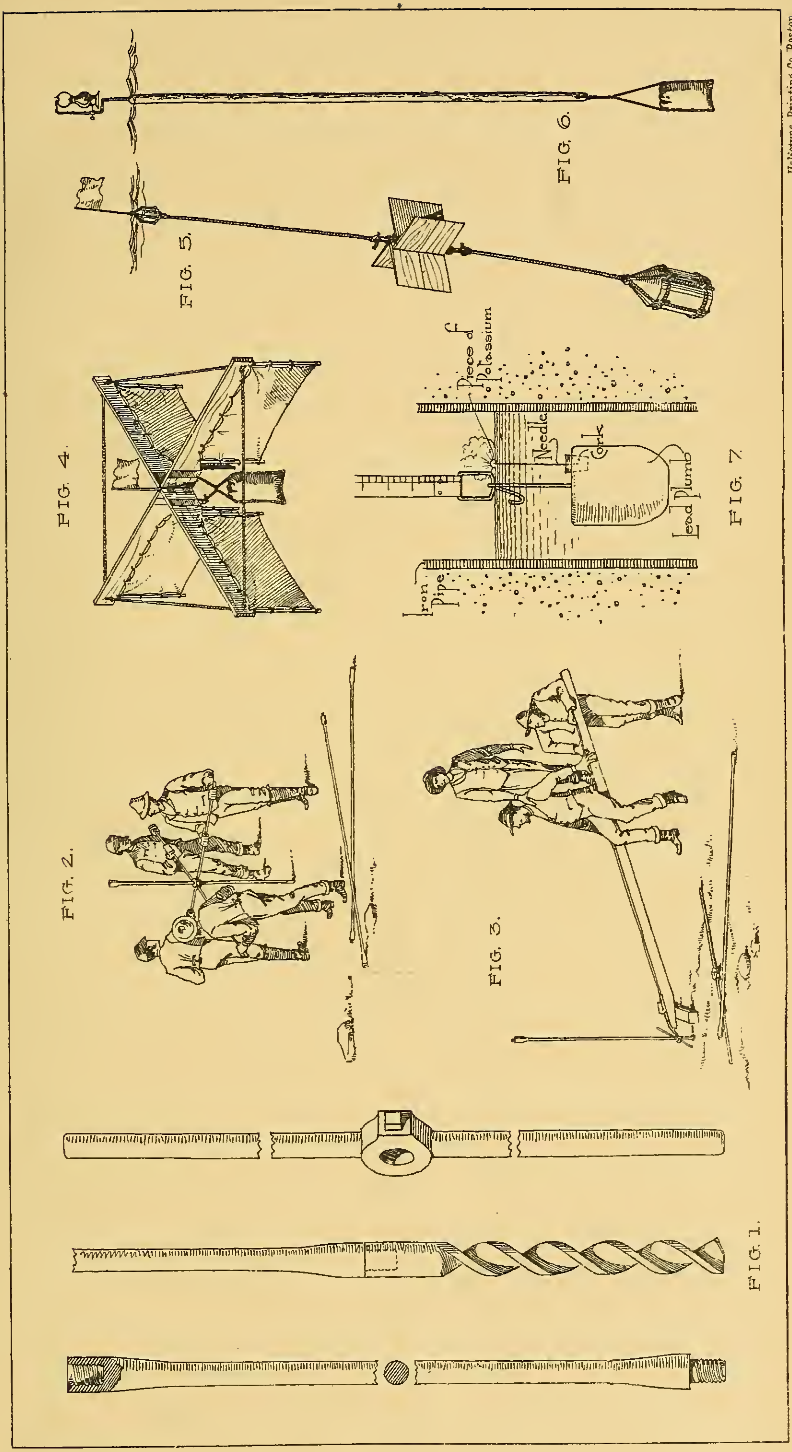
As the location of the outlet would affect materially the whole scheme its consideration received the earliest attention. It was necessary that the discharge should be into favorable currents, and also near a practicable site for a reservoir which could be reached by the outfall sewer from the city. A party for hydrographic work was organized, consisting of one assistant engineer, one additional observer, two sailing-masters, and two boatmen. Their outfit included a small yacht and two tenders.

A projection of the harbor was first made, and the triangulation points given by U.S. Coast Survey were plotted upon it, together with others obtained by ourselves from these, by means of the plane table; the shore line being taken from a chart belonging to the Harbor Commissioners. A sufficient number of prominent points having been determined in this way, it was easy at any time to locate the position of a float by the sextant. At night, when other objects could not be seen, the harbor lights furnished points for observation.

Some difficulty was experienced in deciding upon the best form of float. That first adopted consisted of four radiating arms, with canvas wings projecting downward from them (Plate IV., Fig. 4). Upon calm days this form indicated very fairly the surface velocity; but was too easily influenced by winds and waves to be used in windy weather, as it then invariably grounded on a lee shore.

A "surface and sub-surface" can-float (Plate IV., Fig. 5) was

PLATE IV.



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used somewhat, and gave better results; but an ordinary pole-float (Plate IV., Fig. 6), about 14 feet long and 4 inches in diameter, was finally found to be the most satisfactory, indicating the mean current, which often differed both in direction and velocity from the surface current. This float supported a flag, or lantern, and, when there was danger of its grounding, a shorter one was substituted for it.

In all, about 50 "free-float" experiments were made upon the currents in the vicinity of Moon, Castle, Thompson's, and Spectacle Islands. The trips varied in duration from 6 hours, or one ebb-tide, to 52 hours. Angles to determine the position of the float were taken each half-hour, and were recorded together with the direction and force of the wind and other data. During observations a man was stationed at a tide-gauge, and all velocities were reduced to a mean rise and fall of ten feet. The results obtained from the float experiments, stated briefly, were as follows: —

Favorable ebb currents were found to pass both Moon and Castle Islands. That passing Spectacle Island was sufficient in strength, but unsuitable, owing to its direction and some other characteristics; while that skirting Thompson's Island was altogether unfavorable. Floats leaving the vicinity of Moon Island with the early ebb would travel seawards with an average velocity of .74 miles an hour, passing between Rainsford and Long Islands, through Black Rock Channel, and at the turn of tide would reach a position between the Brewsters and George's Island about four miles from the point of starting. This course is, for its whole extent, outside of the inner harbor. Floats from Castle Island followed Main Ship Channel and Broad Sound, and travelled about as far as those from Moon Island. Returning with the flood-tide the floats would travel about two miles towards the city, and with the succeeding ebb would once more move seaward, not again to enter the harbor.

Sewage, being fresh water, remains for a while at least upon the top of the denser sea-water, and is more affected by surface currents than by deeper ones. An attempt, more interesting than practically instructive, was made to ascertain to what extent sewage put into Boston Harbor would be diffused within a few days. Fifty bottles were put into the water at Moon Island, each containing a postal card, which the finder was requested to mail, stating when and where it was found. Ten of these bottles were picked up within the next three weeks. One of them was found at Marshfield, about 25 miles south of its starting-point; another at Salem, about the same distance north; a third, 30 miles south-east of Cape Ann, and the remaining seven outside of Cape Cod, near Provincetown, Wellfleet, and Chatham, from 50 to 80 miles distant.

Castle Island would have been much more easily accessible from the city than Moon Island, but its selection involved several serious disadvantages. It belongs to the United States, and is the site of Fort Independence. Although this old fort is of little practical value, there were no reasonable grounds for hope that the government would permit a storage reservoir to be located on the island. It would have been necessary to place that structure on the main land in South Boston. The area available for the purpose would have been restricted on account of its great cost. Even if the works could have been so constructed as to be wholly inoffensive, the natural prejudice in the community against the proximity of sewage would have caused great opposition to the building of a reservoir so near to a densely populated district. Moon Island, on the contrary, afforded an excellent site for a reservoir. The neighboring country is sparsely settled, and there is no dwelling within a mile of the works. The outlet, therefore, was finally located at this point.

The next problems considered were the selection of a route for the outfall sewer between the city and Moon Island and the location of the pumping-station. As any route would necessarily cross a portion of the harbor near the mouth of Neponset River, it was thought best to explore the nature of the ground underlying the harbor in that vicinity. To this end a number of artesian borings were made from a scow fitted for the purpose. Five-inch or smaller gas-pipe was driven to the required depth, varying from 20 to 100 feet, and the earth excavated from within them. In all, 139 such borings were made. Those on the line selected by the commissioners, between Fox


CITY OF BOSTON,
MAIN DRAINAGE.
PLAN SHOWING
MAIN, INTERCEPTING & OUTFALL SEWERS,
AND
OLD SEWER OUTLETS.
SCALE.
0 1/8 1/4 1/2 3/4 1MILE
BOSTON HARBOR
CHARLES RIVER
SOUTH BOSTON
CASTLE ISLAND
SPECTACLE ISLAND
THOMPSON'S ISLAND
MOON ISLAND
QUINCY BAY
SQUANTUM NECK
SQUANTUM
SQUANTUM BEACH
DORCHESTER BAY
DORCHESTER
ROXBURY
NEPONSET RIVER
COMMERCIAL POINT
SAVIN HILL
CALF PASTURE
COMMON
PUBLIC GARDEN
BACK BAY
SOUTH BAY
TUNNEL
PUMPING STATION
WEST SHAFT
MIDDLE SHAFT
EAST SHAFT
CITY POINT
OLD HARBOR POINT
FLUME
OLD COLONY R.R.
MT. VERNON ST.

Point and Squantum Beach, showed deep beds of mud underlaid by sand and gravel; so that any method of crossing at that point would have been difficult and expensive. Moreover, Fox Point was thought to be too near to the valuable residence property of Savin Hill to make it a suitable place for a pumping-station. Borings at the mouth of the river opposite Commercial Point also found deep beds of mud, but, the crossing being much shorter, it would have been comparatively easy to have constructed a stable siphon on that line. Commercial Point itself was a fairly good site for a pumping-station, but would have been somewhat difficult of access from the city. Ground suitable for tunnelling was discovered between Old Harbor Point and Squantum Neck. This was the most direct line from the city to Moon Island, and comparative estimates showed it to be also the cheapest line. Its chief merit, however, which caused it to be selected, was that it permitted the use of Old Harbor Point as a site for the pumping-station. This point comprises over 100 acres of marsh land, valued by the city assessors at only $200 an acre. It is itself destitute of habitations, and sufficiently remote from any to afford assurance that operations carried on there will not be a source of offence.

Before adopting the tunnel line a plan was considered by which the sewage, instead of being raised at Old Harbor Point, was to flow thence by gravitation to a pumping-station at Moon Island, on a nearly direct line between the two points. The sewer was to be built above ground and sunk into a trench dug to an even grade in the bottom of the harbor. To determine the feasibility of this plan borings were made to test the nature of the ground on the proposed line. The character of the ground developed by these borings was not considered very favorable, and a decision of the Harbor Commissioners requiring the sewer to be placed lower than was considered practicable caused the proposed plan to be abandoned.

Having decided to locate the pumping-station at Old Harbor Point the routes of the main and intercepting sewers were next selected. The peculiar geological formation of the region about Boston, causing frequent elevation of the bed-rock, not always shown by surface indications, and the sometimes unsuspected presence of deep beds of marsh mud, rendered it necessary to test carefully the nature of the ground through which it was proposed to build the sewers, since its character would form such an important element in their cost and stability. The slowness and expense of artesian methods of boring precluded their use. Light auger-rods were therefore constructed, and it was found that by them the character of the ground could be ascertained with approximate accuracy and with little expense or delay. These tools, and the manner of using them, are shown on Plate IV., Figs. 1 to 3. Including work done before and after the beginning of construction, more than 30,000 lineal feet of borings were thus made, at an average cost of about 25 cents per foot.

There was no trustworthy information extant concerning the position and condition of the city sewers which were to be intercepted. Careful surveys were, therefore, made of about 50 miles in extent, of such sewers as were in the vicinity of the proposed intercepting sewers. Plans and profiles of these were made, with cross-sections and such details of construction as could be ascertained.

Nearly all buildings in the Back-Bay and South-End districts of the city are supported on piles. By city ordinance the tops of the piles are not to be higher than Grade 5, or mid-tide level; in fact many of them are a foot or two higher. Fears were expressed that the intercepting system (by doing away with the semi-daily damming up by the tide of the contents of the sewers) might lower considerably the soil-water in such regions, and, by reducing it below the tops of the piles, cause them to decay and endanger the stability of the buildings supported by them.

To see if such danger was to be apprehended, it was decided to produce in one of the Back-Bay sewers the precise condition which would exist if the new system was constructed, and to notice the effect upon the soil-water. To this end a steam pump was put into the Berkeley-Street sewer near the outlet, and by continual pumping (except at low tide) the sewage was kept but a few inches deep, as it would be if discharging into an intercepting sewer. Previously 20 pipes had been driven below the surface of soil-water; some within a few feet of the sewers, others a few hundred feet away, and still others several blocks distant. The height of the soil-water standing in each pipe was measured twice each day during the continuance of the pumping.

The method of making these measurements was ingenious, and perhaps novel. The elevation of the top of each pipe was known, and the distance from the top to the surface of water was taken with a steel tape. To the bottom of the tape was attached a lead weight, with a needle fixed in its top so adjusted that the point of the needle was just opposite to the end of the tape. A small bit of metallic potassium was put on the point of the needle. The instant this touched the water it ignited explosively, and the flash and sound could be easily distinguished from above. A sketch of the apparatus is shown by Fig. 7, Plate IV.

It was found that the surface of the soil-water was nearly level over the whole Back-Bay district, averaging 7.7 feet above mean low water, and its height, while slightly affected by local contours of the surface, was independent of the sewers in its vicinity. For instance, the water in the vicinity of the Dartmouth-Street sewer was at the same level as that near the Berkeley-Street sewer, although the latter sewer is two feet lower than the former. Also it was found that the soil-water rose and fell, responding quickly to any rain or melting of snow (the extreme rise due to four inches of surface-water being one foot), and that the variation was nearly uniform over the entire district.

Finally it appeared that the pumping, which continued 53 days, affected but slightly, and that only within 100 feet of the sewer, the soil-water in the vicinity of Berkeley Street. At the close of the experiment, the sewer resuming its former conditions, the soil-water in its immediate vicinity rose from an inch to an inch and one-half, and thereafter fluctuated in unison with the water in other localities.

The experiment was thought to show that no dangerous lowering of the ground-water need be apprehended in consequence of the adoption of an intercepting system.

The following was the general basis of calculations for amounts of sewage and sizes of sewers. It was necessary to assume some limit to the territory which should be tributary to the intercepting system. A natural limit in this case seemed to be afforded by the Charles and Neponset Rivers, which, with Mother Brook connecting them, include an area of about 58 square miles. Of this area about 46 square miles is high land, 40 or more feet above low water, and, as suggested by the commissioners, drainage from districts above Grade 40 could, if necessary, be intercepted by a "high-level" intercepting sewer and could flow by gravitation to the reservoir at Moon Island. There remain 12 square miles below Grade 40 which must forever drain into the "low-level" system. As, however, it will be long before the high-level sewer is built, and in the mean time sewers from areas above Grade 40 must connect with the low-level system, for purposes of calculation, it was assumed that 20 square miles would be tributary to the proposed system.

The prospective population was estimated at an average of $62\frac{1}{2}$ persons to each acre, or 800,000 in all. This estimate of $62\frac{1}{2}$ persons to the acre was used in calculations affecting the main sewer; but in proportioning branch intercepting sewers greater densities of population were assumed, to provide for possible movements of population. The amount of sewage per individual was estimated at 75 gallons, or 10 cubic feet, in each 24 hours. The maximum flow of sewage per second was estimated at one and one-half times the average flow due to 10 cubic feet per day.

On this basis the maximum flow of sewage-proper to be provided for would be $\frac{800,000 \times 10}{24 \times 60 \times 60} \times 1.5 = 138.88$ cubic feet per second.

This amount was nearly doubled by adding to it 100 cubic feet per second as a provision for rain-water. This would represent a little less than one-fourth inch of rainfall in 24 hours, per acre of tributary area; but it was intended, in practice, to admit little, if any, rain from regions where the cellars were not subject to flooding, and reserve the full capacity of the sewers and pumps to relieve certain low districts where the cellars are generally much below high tide, and were often partly filled with water in time of rain.

For purposes of calculation, therefore, the prospective maximum flow per second in the main sewer was assumed to be $138.88 + 100 = 238.88$ cubic feet per second. The inclination of the sewer was 1 in 2,500, and it was designed (as were all of the sewers) to flow about half full with its calculated maximum amount of sewage. Although this rule required that the sewers should be larger than they would be if designed to flow full, it was adopted, because it gave about three feet less depth of excavation for the whole sewer system, saved three feet lift in pumping, provided storage-room for large additional amounts of sewage due to intermission of pumping or to rain, and afforded more head-room to workmen entering the sewers.

In designing the smaller intercepting sewers the method employed was somewhat as follows: the districts drained by the several city sewers were ascertained, and their respective areas in acres were calculated. The largest population which by any chance might live on these areas in the future was estimated, *i.e.*, guessed. The future average amount of sewage-proper due to such population was doubled for safety, and an additional amount added for rain, usually equalling that from .25-inch rainfall in 24 hours. If an intercepting sewer large enough to carry this total amount when flowing half full would have been too small to be entered conveniently, its size, or sometimes only its height, was increased sufficiently to afford convenient head-room.

Velocities of flow were calculated by the formula $V = C\sqrt{RI}$, with Mr. Kutter's coefficients, obtained by using .013 as the coefficient for roughness.

During the early stages of the work, the City Engineer, Mr. Davis, made a trip to Europe to examine the foreign sewerage works of best repute. Information was thus gained which was used in designing the Boston works.

In July, 1877, the City Engineer reported the results of his preliminary survey, and on August 9 of the same year orders of the City Council were approved, authorizing, and making an appropriation for, the construction of an improved system of sewerage, in general accordance with the proposed plan, under authority of the Act of Legislature.

The City Council committed the charge of building the Main Drainage Works to a Joint Special Committee on Improved Sewerage, consisting of three Aldermen, and five members of the Common Council. This committee changed its membership every year except when one or more of its members were reëlected and were again appointed on it. By city ordinance all engineering works are built by the City Engineer. The Main Drainage Works, therefore, were constructed under the direction of Mr. Joseph P. Davis, C.E., City Engineer, until his resignation in 1880, and since that date by his successor in office, Mr. Henry M. Wightman, C.E.[1]

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[1] Since the above was written the city has sustained a great loss in the death of Mr. Wightman. Mr. William Jackson has been elected City Engineer.

CHAPTER V.

MAIN SEWER.

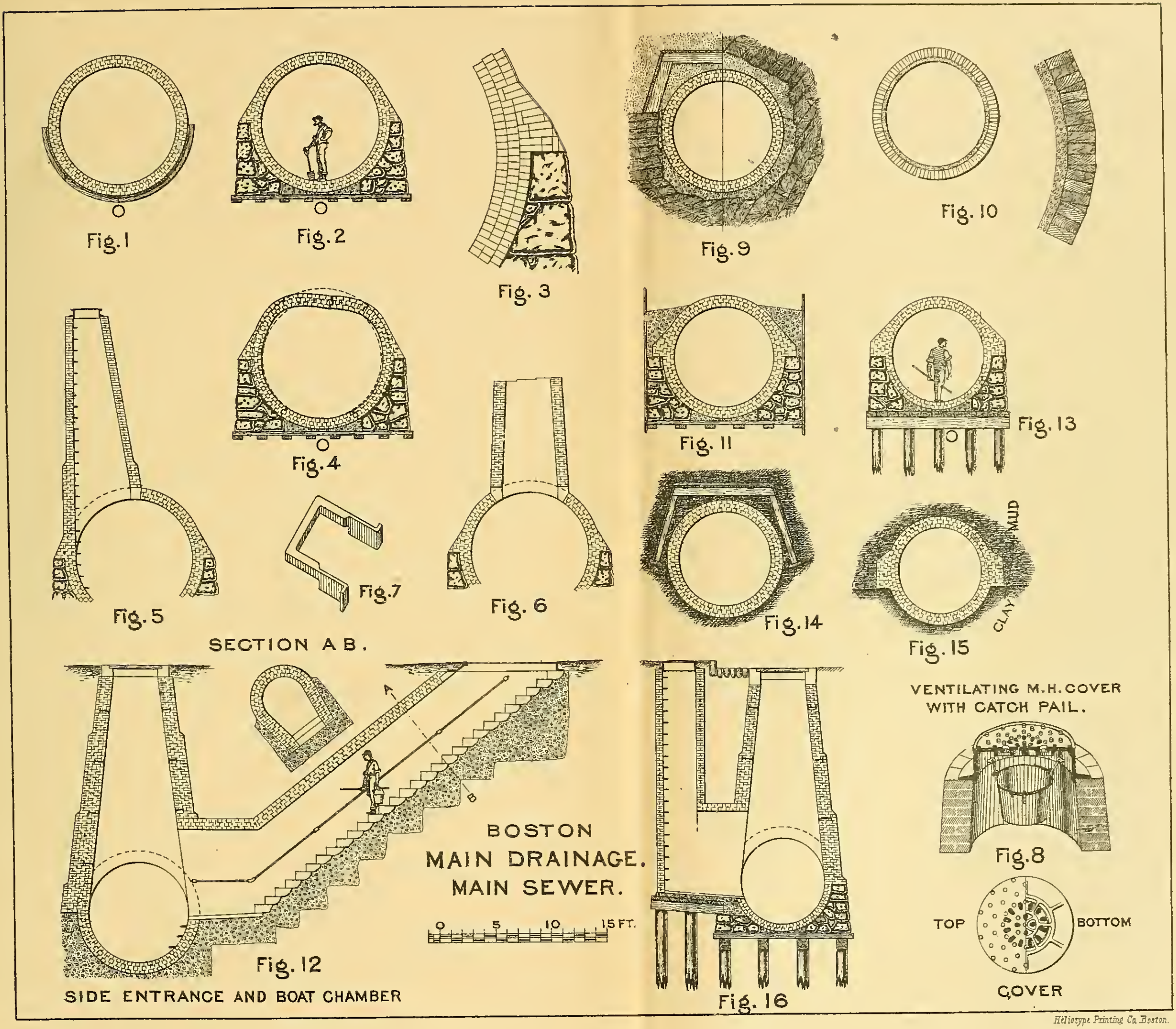
The main sewer is about $3\frac{1}{4}$ miles long, and extends from the pumping-station at Old Harbor Point to the junction of Huntington Avenue and Camden Street. Its inclination throughout its whole extent is 1 foot vertical in 2,500 horizontal. At the pumping-station the water-line of the invert, *i.e.*, its bottom, is about 14 feet below the elevation of mean low tide. From this point, in its course towards the city, the sewer passes for about a mile across the Calf Pasture Marsh, so called. The surface of this marsh is about six inches above mean high water, and, the mere rise and fall of the tide being ten feet, the average depth of excavation required for this section of work was 24 feet. Up to the junction of the South Boston intercepting sewer the main sewer is ten feet six inches in diameter. It was founded sometimes upon clay, and sometimes upon sand. Figs. 1 and 2, Plate VI., show the usual methods of construction. Rubble side walls were built for the greater portion of the distance. Fig. 3 shows the bond used in the spandrels.

On this section occurred the only case during the construction of the entire Main Drainage Works in which a sewer was broken so that a portion of it had to be taken down and rebuilt. At one point, for a distance of 150 feet, the marsh mud, which usually was from five to ten feet deep below the surface of the ground, came down below the spring-line of the sewer. Owing to carelessness, on the part of the contractor, in back-filling around the haunches, or in withdrawing the sheet planks, the sewer spread six inches, and sank correspondingly at the crown. Fig. 4 shows the shape assumed at the point of maximum distortion. Although even this portion was probably stable, it was not considered wise to establish a precedent of accepting any imperfect work. Accordingly the trench was reopened, the sewer uncovered, and its arch broken down with sledge hammers.

It was found that the 12-inch Akron drain-pipe built under the sewer, to facilitate drainage of the trench during construction, was broken at this point, and the water from it, accumulated from 4,000 feet of trench, found an outlet, and poured over the side walls into the invert. This water was controlled by pumps, but was found to have washed out a quantity of sand, causing a considerable cavity under the sewer platform. The limits of the cavity having been determined, five holes, ten feet apart on centres, were made through the bottom of the sewer, and 3-inch wrought-iron gas-pipes were inserted into them. Two of these pipes were about 30 feet long, and three others, for vents, were five feet long. Constant streams of grout, made from 47 casks of neat, quick-setting Portland cement, were forced under a 25-foot head, through the long pipes into the cavity until it was filled, as proved by the cement rising in the short pipes. The grout hardened and furnished a secure foundation. Special ribs were cut to fit the invert, which was again arched over and the trench refilled.

Figs. 5 and 6, Plate VI., show methods of connecting man-holes with the main sewer. These structures are about 400 feet apart, and are placed alternately on one side of and over the centre of the sewer. At man-holes the arch is supported by cut-granite skewback stones. At the top of the man-holes are cast-iron frames supporting circular iron covers. The covers are perforated for purposes of ventilation. The holes are quite large, so that they are not liable to become stopped up. They also taper considerably, being larger below than they are on top. To prevent road detritus and miscellaneous rubbish from falling into the sewers, catch-pails are suspended below the covers to receive whatever may fall through the holes. The pails are of galvanized iron, well coated with tar. They can be lifted up, emptied, and replaced, as occasion demands. Wrought-iron steps were built into the man-holes during construction. These details are shown on Plate VI., Figs. 7 and 8.

Above the point where the South Boston intercepting sewers join the main sewer the latter is nine feet in diameter. For about half a mile the ground is high, but a location through



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it could not be avoided without making a considerable detour. For 1,900 feet, in Mount Vernon Street, the sewer was built by tunnelling through conglomerate rock and coarse sand. The rock, where it surrounded the tunnel, presented no serious obstacle; but the sand tended to run into the excavation, and required close sheeting and heavy bracing to support it. Fig. 9, Plate VI., shows the sewer in tunnel on this section. For several hundred feet the sewer grade was near the surface of the ledge and, the latter being very irregular and covered with boulders, tunnelling operations were attended with much difficulty, and several caves occurred. For a length of 160 feet the ground was opened from the top and the sewer was built in an open trench about 45 feet deep.

The sewer in the tunnel was well built, but after completion, on removing the pumps so that the water table in the vicinity was permitted to rise above the sewer, the latter was found to leak a good deal. The leaks, however, could be successfully calked. The process consisted in raking out a joint, where a leak occurred, to the full depth of the brick and driving in sheet lead for half the depth, the remainder being filled with cement.

Excepting a section in East Chester Park, from Clapp Street to Magazine Street, the main sewer was built by contract. The laying out as a street of East Chester Park, east of Albany Street, had been contemplated by the authorities for some time, and action to that end was taken in time to permit the sewer being located there. The borings on this line showed that there were beds of marsh mud between Clapp and Magazine Streets which were from 20 to 86 feet deep below the marsh surface. As it would have been difficult to build a stable sewer in such ground, and impossible to prevent one, if built, being destroyed when the street should be filled over and around it, it was decided to fill the street to full lines and grades before attempting to build the sewer.

A contract was accordingly concluded by which the street was filled with gravel brought by the N.Y. and N.E. Railroad. So great was the settlement of this filling into the mud that over 106,000 cubic yards of gravel were required. The marsh level for 100, or more, feet on either side of the filled street was pushed up by the filling from 8 to 14 feet high. A surcharge, 20 feet wide on top and 8 feet high, was put upon the street west of the N.Y. & N.E. Railroad, where the mud was deepest, to insure prompt settlement.

Building a stable sewer in a street so recently filled being a difficult operation, requiring methods of treatment which cannot be determined upon beforehand, it was thought best to build this section by day's labor.

As a masonry structure would have been broken when the trench was refilled, a wooden sewer was adopted (Fig. 10, Plate VI.). This consisted of an external wooden shell, formed of 4-inch spruce plank, ten inches wide, every fourth plank being wedge-shaped; the whole securely spiked and treenailed together and finally lined with four inches of brick or concrete masonry.

The depth of excavation for this sewer was from 32 to 36 feet, and the pressures were so great as to require very heavy bracing. As many as 60 braces of 8 inch × 8 inch, or heavier timber, were sometimes used for a length of 18 lineal feet of trench; and these, when taken out, were all found to be either broken or so crippled as to be unfit to use again. Frequently the earth on one side of the trench was found to be different from that on the other, which caused very unequal pressures, so that internal bracing was necessary to maintain the sewer in its proper shape until the trench had been back-filled. It was found necessary to build the shell with a vertical diameter four inches greater than was required for the masonry lining, to allow for settlement, change of shape, and compression of the timber. The vertical diameter inside of the lining was also increased, so that, if in places the sewer should settle as a whole, the bottom could be brought to the true grade, and still leave the established sectional area.

The length of this section was 1,894 feet. Ground was first broken in August, 1879, and the work was completed in October, 1880. For excavating and back-filling the trench, machinery designed by the Superintendent, Mr. H. A. Carson, was used. The average cost per lineal foot of the completed sewer was $56. For several hundred feet, where the mud had been deepest, a continual slight shrinkage and settlement of the gravel filling under the sewer occurred for a year or more. The sewer itself, also, settled in a long curve, whose greatest depth below the original grade line was about 18 inches. A masonry sewer would have been broken by such movement, but the wooden one, having considerable flexibility, was apparently uninjured. At present (1885) the street seems to have assumed a condition of permanent stability.

In East Chester Park, from Magazine Street to Albany Street, clay was chiefly encountered, and the sewer generally consisted of a simple ring of brick-work without side walls, and its construction presented few features of special interest. As a precaution in passing within 35 feet of a large gas-holder, tongued and grooved 4-inch sheet planks were driven, and the trench was back-filled with concrete to the crown of the sewer arch (Fig. 11). In passing across the old Roxbury Canal, which had been recently filled by the city, an influx of tide-water along the loose walls of the canal and through the filling occasioned some delay and expense. The water was finally kept out by double rows of tongued and grooved sheet-piling. A side entrance and boat-chamber (Fig. 12) were built on this section, at the corner of Swett Street. The latter structure resembled a very large man-hole, with a rectangular opening from the street, 11 × 4 feet in dimensions. This was built to allow the lowering of boats into the sewer.

At Albany Street the East Side intercepting sewer joins the main, and above this point the latter is again reduced in size, to eight feet three inches wide by eight feet five inches high. The extra horizontal course was put in at the spring line because it was supposed to facilitate dropping and moving the centres. In East Chester Park, and Washington Street from Albany to Camden Street, the sewer was built chiefly in clay, and consisted of a ring of brick-work. For about 300 feet, however, near Albany Street, mud was found, and a foundation, consisting of a timber platform supported on piles, became necessary (Fig. 13, Plate VI.).

In Camden Street, from Washington Street to Tremont

Street, a distance of 1,391 feet, the depth of trench required would have been 26 feet. Camden Street is rather narrow, and contains sewer, gas, and water pipes. As good clay was found at a depth five or more feet above the top of the sewer, it was thought that it would be as cheap to the city, and decidedly less annoying to residents on the street, to build the sewer by tunnelling beneath the surface (Fig. 14). Working shafts were sunk about 250 feet apart, and headings in each direction driven from them. At one or two points the miners permitted the roof of the tunnel to settle slightly, by which the common sewer above was cracked, and some trouble caused by the sewage leaking into the tunnel. The main sewer was back-filled above the arch with clay, packed in under the lagging as firmly as possible. On the whole the method of construction was successful, and a well-built sewer was obtained. Its cost was $22.52 per lineal foot.

At Tremont Street, the Stony-Brook intercepting sewer is taken in. At this point, as at all other places where intercepting sewers join the main sewer, the grade of the latter rises abruptly somewhat less than a foot, or enough to maintain the established inclination on the surface of the sewage at the time of maximum flow. From Tremont Street to the present end of the main sewer, at Huntington Avenue, the sewer was built in open cut (Fig. 15), and for a large part of the distance needed side walls and piling for its support. Just west of the B. & P. R.R. another boat-chamber and side entrance (Fig. 16) were built, and a third side entrance, reached by a stone stairway leading from the sidewalk, was constructed at Huntington Avenue.

The total cost of the 3.2 miles of main sewer was $606,031, being an average of $36.09 per lineal foot.

CHAPTER VI.

INTERCEPTING SEWERS.

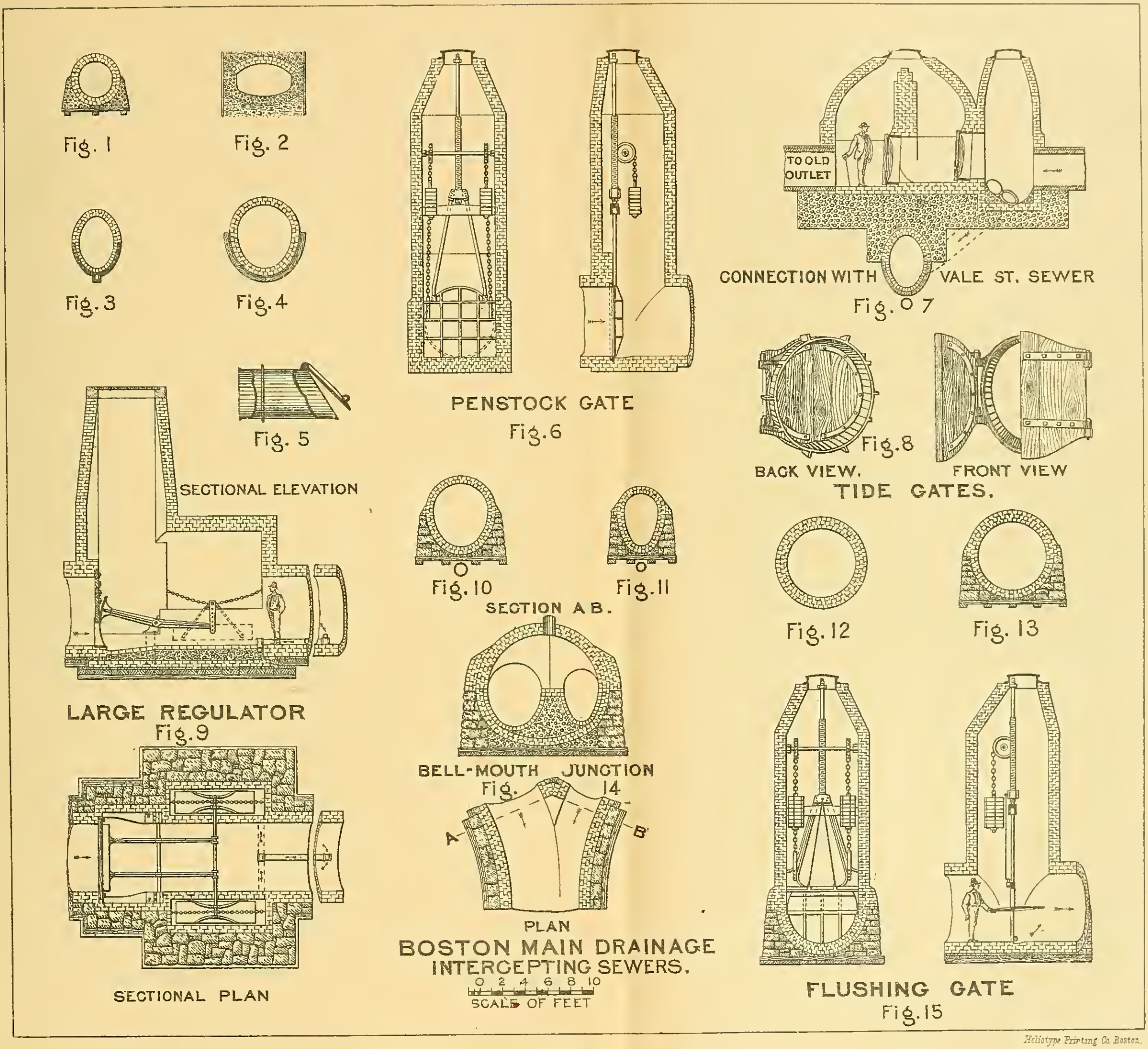
As before stated, and as shown by the plan (Plate V.), the South Boston intercepting sewer is the first to join the main sewer in the latter's course from the pumping-station towards the city proper. This intercepting sewer, by its two branches, is intended finally to encircle the peninsula on which South Boston is situated, and intercept the sewage flowing in the common sewers, which have heretofore discharged their contents at nineteen outlets, in the immediate vicinity of a dense population.

At the point of junction the grade of the intercepting sewer is 1.5 feet higher than that of the main sewer, so that the sewage in the former shall not be dammed back, and the established rate of inclination shall be maintained on the surface of the sewage in both sewers at the time of maximum discharge. In all cases where a main drainage sewer joins another the junction is made at a "bell-mouth" connection chamber, in which the axes of the sewers meet by lines or curves tangent to each other, so that the two currents may unite with the least disturbance to either. Sections of the "bell-mouth" junction of the two branches of the South Boston sewer, at Hyde Street, are shown by Fig. 14, Plate VII. On each intercepting sewer, just before it reaches the main sewer, is built a penstock chamber, containing a cast-iron penstock gate, by which the flow can be cut off, so that the main sewer can be entirely emptied, should it ever be desirable to do so. At such times the city sewage would be discharged at the old outlets, which are all retained and protected by tide-gates. A sketch of the penstock on the South Boston sewer is given by Fig. 6.

Up to where it divides this sewer is circular, six feet in diameter. The average depth of excavation was 20 feet. Clay or sand was usually found, and the sewer consists of a simple ring of brick-work, 12 inches thick, though for about 350 feet, where the sand was wet and inclined to run, abutment walls of rubble masonry were used. Figs. 12 and 13 show cross-sections of this sewer. The brick invert was laid with Portland cement mortar, one part cement to two parts sand, and the arch was laid with American (Rosendale) cement mortar, one part cement to 1.5 parts sand. This was the common practice in building the main drainage sewers, Portland cement being used in the inverts, on account of its greater resistance to abrasion. When Rosendale cement was used for building inverts, the proportion required was equal parts of cement and sand.

The inclination of this sewer throughout the greater portion of its extent is 1 in 2,000, which affords a velocity of flow sufficient to prevent deposit of sludge, but not sufficient to keep in suspension sand and road detritus. A sharper inclination would have been desirable had it been practicable to obtain one. Few of the main drainage sewers have a greater inclination than 1 in 2,000, and it was expected from the first that flushing would occasionally be required to prevent the accumulation of deposits. To provide for this, iron flushing-gates are built into the sewers at intervals of about half a mile. The first flushing-gate on the South Boston sewer is just below the fork at Hyde Street. A sketch of this gate is given by Fig. 15. Usually the gate stands above the sewer, in the man-hole. It is kept vertical by two small stop-bolts at its top. To flush the sewer the gate is lowered against its seat, built into the bottom of the sewer, and the sewage accumulates behind it as deep as the gate is high. The stops are then withdrawn and the gate raised until it clears its lower seat, when it tilts over into a horizontal position and opens a free passage for the dammed-up sewage.

The greater part of South Boston is high land, and there are but few low cellars there which are subject during rain-storms to flooding at high tide. In order that the full capacity of the sewers and pumps might be available to relieve other parts of the city, less favored in this respect, it was necessary to arrange that no more than a fixed quantity of sewage should ever be received by the main sewer from the South Boston



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intercepting sewer. To accomplish this a "regulator" was built into the intercepting sewer just below its last connection with a common sewer, at Kemp Street.

A sectional plan and elevation of this machine, and of the chamber containing it, is given by Fig. 9, Plate VII. As will be seen, the apparatus is very simple, and consists of stop-planks, closing the sewer from its top down to about the ordinary dry-weather flow line, the sewer below the planks being lined with a cast-iron gate frame, or seat, curved to fit the invert, and also vertically to correspond with the curve of motion of a cast-iron valve, which plays up and down in front of it. The valve is held by two cast-iron levers, pivoted by a 3-inch wrought-iron shaft in two bearings, the other ends of the lever being connected by vertical arms to a 3-inch square bar. To the ends of this bar are fastened two boiler-plate floats, placed in wells on either side of the sewer. To avoid disturbance to the motion of the floats, by waves caused by the rush of sewage under the valve, water is brought to the wells through a 5-inch pipe, as shown, from a point 50 feet below the regulator.

The connection between the valves and the floats can be so adjusted that the former will begin to close when the surface of sewage in the sewer has reached any desired height. As the floats rise the valve descends until the opening below it is just sufficient to let enough sewage pass to maintain the allowed depth of flow in the sewer. Should the amount of rain-water from low districts, reaching the main sewer through other intercepting sewers, exceed the capacity of the pumps to control it, the main sewer fills, and its sewage backs up into the South Boston sewer, and still further raises the floats. The opening under the stop-planks is thus entirely closed, and all of the common sewers above discharge at their old outlets, and continue to do so until the amount of water reaching the pumps can be controlled by them.

Above where this sewer divides, at Hyde Street, the branch which turns to the right, and skirts the southerly margin of South Boston, is egg-shaped, four feet six inches high by three feet wide (Fig. 11, Plate VII.). After passing under the

Old Colony Railroad the shape is changed somewhat (Fig. 3). At Vinton, Vale, and other streets common sewers are intercepted. Fig. 7, Plate VII., shows the connection with the Vale-Street sewer, and may stand as a type of such connections between common and intercepting sewers, whenever no regulation of the amount to be received from the former is required. Nearly every individual case presented special conditions, which necessitated some modification of the method of construction; but the general plan was the same in most cases, and its features are shown in this case.

A sump hole, two feet deep, into which the sewage falls, is first built in the common sewer. Into the bottom of this sump is built a short section of iron pipe (Fig. 5), from 12 to 24 inches in diameter, protected by a cast-iron flap-valve. Ordinarily this valve stands open, but can be closed if it is desired to break the connection between the two sewers. The bottom of the sump, around the pipe, is rounded off with strong Portland cement concrete, so that there shall be no corners in which deposits can lodge. The sewage passes to the intercepting sewer through a short branch connecting with the lower end of the iron pipe.

Beyond the sump the common sewer is provided with a chamber containing a double set of tide-gates. These gates give a clear opening of from two to four feet diameter. Each set of gates is hinged to a cast-iron ring, or gate seat (Fig. 8), which is built into the brick-work. The two wooden gates close against each other. To make tight joints the bearing surfaces of the gates are covered with strips of rubber about three-eighths of an inch thick. The gates are inclined somewhat, so that they are self-closing.

From the main sewer to the Old Colony Railroad this intercepting sewer was built by contract, at an average cost of $12.68 per lineal foot. From the railroad to H Street it was built by day's labor, and cost $13.25 per lineal foot. On Ninth Street, between Old Harbor Street and G Street, for a distance of about 800 feet, the sewer location crossed a beach which was several feet below high-tide level. No coffer dam or other protection was used in this place, but construction was carried on only when the tide was down. When the sea rose it overflowed and filled the trench. When it again fell the water in the trench was let off, through the sewer already built, to pumps at the pumping-station, and work was resumed. From H Street to N Street, on Ninth Street, the sewer was built by contract. For about 1,000 feet, near K and L Streets, the average depth of the trench was about 27 feet. The sewer was nearly circular, three feet wide and three feet two inches high (Fig. 1, Plate VII.). This section was among the earliest built, and its design is not in accord with later practice. It might have been made much more convenient for workmen to enter, at slight additional expense, by giving it a greater vertical diameter. Its fall is 1 in $1,666\frac{2}{3}$.

From the point of division on Hyde Street the sewer which turns to the left, and follows the westerly shore of South Boston, is egg-shaped, five feet six inches by four feet nine inches, up to the Old Colony Railroad crossing, on Dorchester Avenue. A timber platform and rubble masonry side walls were required for the entire distance, and the usual cross-section of this sewer is shown by Fig. 10, Plate VII. This section was built by contract. Its length is 3,350 feet; the average depth of excavation was about 24 feet, and the average cost per lineal foot was $16.85.

After taking in the B-Street sewer the intercepting sewer changes its shape (Fig. 3), and continues in Dorchester Avenue, passing under the N.Y. & N.E. Railroad, and turns into Foundry Street, which it follows to its end, at the corner of Dorchester Avenue and First Street. Considerable difficulty was encountered in passing under the abutments of the bridge on Dorchester Avenue, over the N.Y. and N.E. Railroad. These were underlaid by running sand, and the northerly abutment over the sewer, which had been built without mortar, had to be taken down. Under the tracks of the same railroad, head-room being limited, the shape of the sewer was altered (Fig. 2), so that there should be no danger of its interfering with, or being injured by, repairs to the road-bed. This section of sewer is 2,820 feet long, and its average cost per foot was $19.25.

The second large intercepting sewer which enters the main sewer had its point of connection at the intersection of East Chester Park and Albany Street. It is called the East Side intercepting sewer, and is located in streets following the easterly margin of the city proper for a distance of about $2\frac{1}{4}$ miles. In Albany Street, from East Chester Park to Dover Street, a distance of 4,524 feet, the sewer is nearly circular, with a vertical diameter of five feet eight inches, and a horizontal one of five feet six inches. The inclination is 1 in 2,000. The average depth of excavation for this section of work was 24 feet, and, as marsh mud and peat extended from near the surface of the ground to a depth always considerably below the bottom of the sewer, piles were required to furnish a secure foundation. A timber platform was fastened to the tops of the piles, and on the platform the sewer, with its rubble masonry abutment walls, was built. The bottom of the excavation was about 6.5 feet below the elevation of low tide, and considerable trouble was experienced from sea-water making its way into the trench, especially in places where old sea-walls and other such obstructions were encountered. The mud on the sides of the trench exerted much lateral pressure, and close sheet-piling and heavy bracing were necessary. Opening so deep a trench in such material drained the water out of the adjacent soil, rendering it spongy and somewhat compressible, so that the whole street settled and had to be resurfaced and repaved. This section was built by contract. One firm of contractors gave up the job, and the work was re-let under provisions of the contract. The average cost per lineal foot of the completed sewer was $26.16.

The first common sewer taken in by the intercepter is that on Concord Street. This sewer drains a district in which the cellars are not subject to flooding from rain-water during high tides. It was not necessary, therefore, to let this sewer discharge into the intercepter an amount of sewage in excess of its ordinary maximum dry-weather flow, and temporarily, during rain-storms, the whole dilute contents of the sewer could, without injury, be permitted to discharge into the bay at the old outlet. An arrangement to effect this was desirable, because, during very heavy rain-storms, the whole capacity of the intercepting sewer might be needed to afford relief to sewers draining low districts beyond Concord Street.

Accordingly the connection between this sewer and the intercepting sewer was made through a chamber containing a small regulating apparatus, designed to control or cut off the flow automatically. Figs. 1 and 2, Plate VIII., show sections of this apparatus and its arrangement. Eight similar appliances, with slight modifications in the methods of arrangement, were used in connection with the same number of common sewers.

The operation of the apparatus will be understood from an examination of the figures. Under ordinary circumstances the sewerage falls into a sump, and thence passes to the regulating chamber, which it enters through a cast-iron nozzle. This nozzle is circular, 12 inches in diameter at its upper end, and rectangular 20 × 6 inches at its orifice. In front of the orifice plays a cast-iron valve, moved by a float in a tank set in the floor of the chamber. The water in the tank stands at the same elevation as that in the intercepting sewer, a 4-inch iron pipe connecting one with the other. The apparatus can be adjusted so that the valve will begin to close and cut off the flow of sewage when the water in the intercepting sewer reaches any desired depth. When not cut off, the sewage flows around the tank and passes on through an opening at its further end.

The second common sewer taken in is that in Dedham Street. This sewer drains a district which used to suffer greatly from flooding during rain-storms. In order to afford relief this sewer was connected directly with the intercepter by a branch two feet in diameter, the inlet to which is never closed.

The third sewer taken in is that in Union Park Street. The district drained by it has suffered but slightly from wet cellars, and that only during severe storms and very high tides. The flow from this sewer was regulated in the same manner as that from the Concord-Street sewer, but the apparatus was so adjusted that it cuts off the flow later than in the case of most other sewers, and only when the intercepting sewer is nearly full.

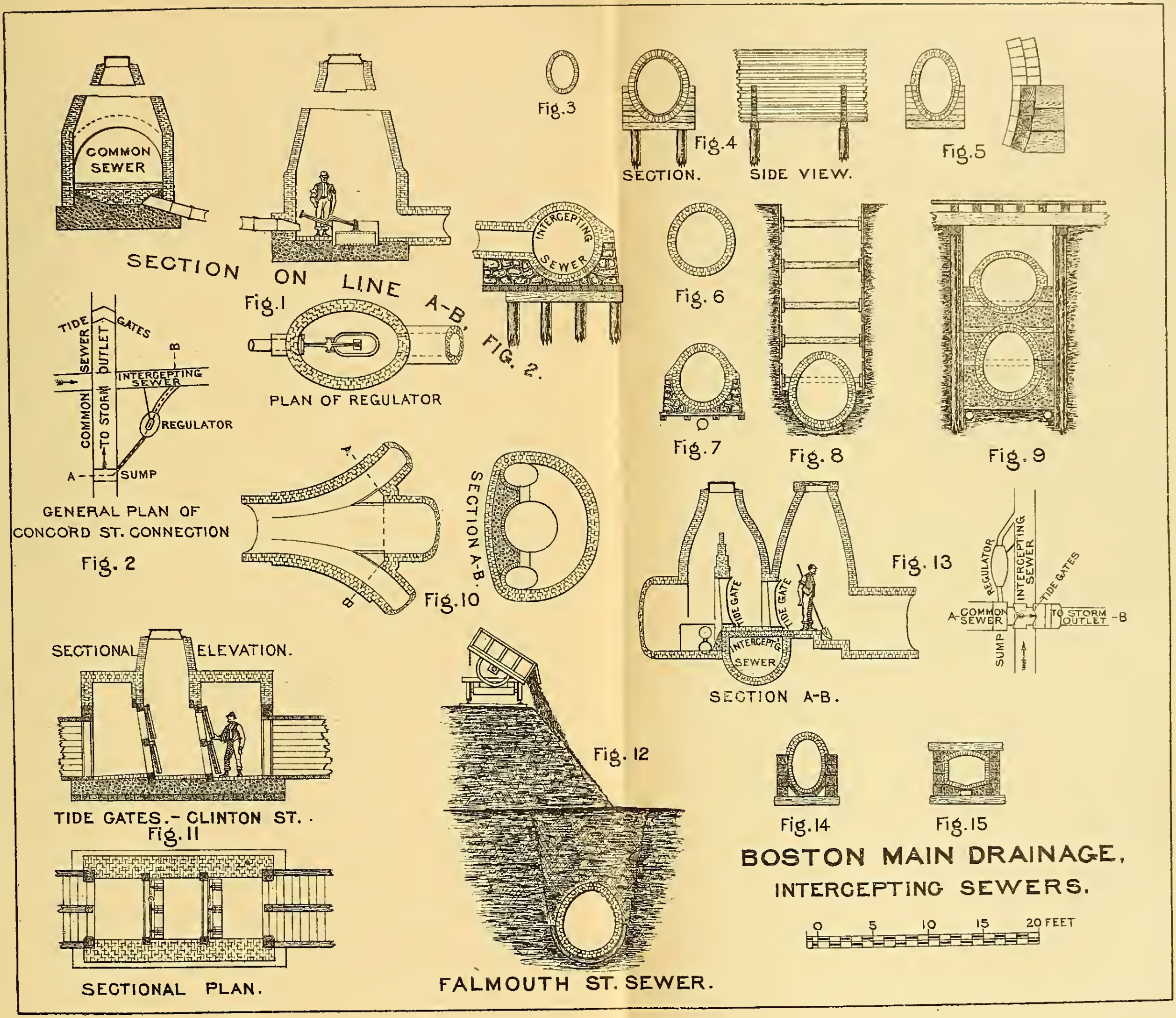
The fourth common sewer met with is that in Dover Street.

This drains a low district, and a free connection, two feet in diameter, was made with it. According to the usual practice in such cases this sewer would have been connected with the intercepter at or near the point in Albany Street where their two locations intersect. But it was found in examining the city sewers, with reference to connections with them, that the Dover-Street sewer was not in condition to be intercepted at any point east of Harrison Avenue. Between that street and its outlet it is a rectangular wooden structure, 5 × 6 feet in dimensions, placed close to an old stone retaining-wall and surrounded by loose stone ballast. It is considerably broken, so that the tide-water from the bay which ebbs and flows about the wall and in the ballast has free access to the sewer, and would have flowed into the intercepting sewer, and so reached the pumps. From Harrison Avenue westerly, the Dover-Street sewer was built of brick, and was tight so that sea-water could be excluded from it by tide-gates. Accordingly the connection was made west of Harrison Avenue, and a 2 × 3 feet oval branch sewer (Fig. 3), 588 feet long, was built from that point to convey the sewage to the intercepting sewer at Albany Street.

Above Dover Street are few districts which suffer from flooding. Accordingly a large regulating apparatus, to control the flow from above, was built into the intercepting sewer at this point. It resembled that on the South Boston sewer, before described, and shown on Plate VII. by Fig. 9.

From Dover Street to its upper end on Atlantic Avenue the East Side sewer was built by day's labor, under a superintendent appointed by the city. This was done because above Dover Street the sewer location was confined to crowded thoroughfares, in which peculiar management was required to prevent serious obstruction to travel and to the business of abutters; and also because, operations being principally carried on in filled land, beds of dock mud, old walls, wharves, and other obstructions were continually encountered, requiring frequent changes in methods of construction which could not be foreseen and provided for in the specifications of a contract.

From Dover Street the sewer location extends in Albany



BOSTON MAIN DRAINAGE,
INTERCEPTING SEWERS.

Street to Lehigh Street, at which point it enters private land, and crosses the freight and switch yards of the Boston and Albany, and Old Colony Railroads, to Federal Street, near the bridge, a total distance of 2,331.5 feet. In Albany and Lehigh Streets are the tracks of a Freight Railway Company, and in the railroad yards are about 40 lines of rails in constant use, which it was very important should not be disturbed. The whole section of work is in filled land, underlaid by beds of mud, from 5 to 20 feet deep, below the bottom of the sewer, which is itself several feet below the level of low tide. At different points obstruction in the shape of old walls and wharves were encountered, which admitted sea-water freely to the trench, so that, as a rule, work could only progress during low stages of the tide.

The sewer is oval, five feet high (Fig. 4), and generally required piling for its support. It is built partly of wood, lined with two inches of concrete, and partly of brick-work resting on a solid cradle of wood, six inches thick. Travel upon the streets was not interrupted, and with considerable difficulty the freight-railway tracks were supported and maintained. As it would have been impossible to have had an open trench through the Albany and Old Colony Railroad yards without interfering with their traffic, operations at that point were carried on entirely below the surface. The tracks were supported by stringers, and the spaces between them floored over. By the use of special machinery all the earth excavated or refilled, as well as materials for constructions, was conveyed by tracks suspended below the floor. The trench was well braced, and its sides protected by lag-sheeting, which, together with the piles driven to support the sewer, were all put in place without encroaching upon the surface. It is believed that not a single train was delayed, nor any inconvenience caused, by these operations. The average cost of this section of sewer was about $31.26 per lineal foot.

In Federal Street, and Atlantic Avenue to its end at Central Street, the intercepting sewer is oval, four feet six inches high by two feet eight inches wide. Fig. 5, Plate VIII., shows the usual mode of construction. Federal Street contained double horserailroad and single freight-railway tracks, and beneath its surface were one sewer, two water-pipes, and two gas-pipes. Beds of dock mud extended from 5 to 20 feet below the bottom of the new sewer, and old dock walls and timber structures were frequently encountered. A location on the east side of the street was found to be most practicable, and the sewer was built by methods which left the roadway open for travel. By flooring over the trench at intervals, passages were maintained through the excavating machine (shown on Plate XXV.) to the yards and wharves bordering Fort Point Channel.

The freight-railway tracks were shifted towards the centre of the street, and were used during the day for the passage of horse-cars in one direction. Bricks, cement, and other material were piled on the outer edges of both sidewalks where they would cause least inconvenience, and always so as to leave a clear passage-way four feet wide. Endeavors were made to cause the least possible annoyance to corporations and individuals; and in general these efforts seemed to be appreciated and reciprocated by the public, so that complaints were rare. This section of work was 5,159 feet long. The average depth of excavation was about 21 feet, and the average cost of completed sewer was $15.06 per lineal foot. The Stony-Brook intercepting sewer joins the main sewer at the intersection of Camden and Tremont Streets. This sewer intercepts the sewage which formerly emptied at seven outlets, into Stony Brook, and thence found its way into the Back Bay. In Tremont and Cabot Streets, from Camden to Ruggles Street (Plate V.), a distance of 2,135 feet, the sewer was built by contract. The rate of inclination is 1 in 700, and the average depth of excavation required was 21 feet. The sewer is nearly circular, four feet six inches wide by four feet eight inches high, and is chiefly founded on clay, so that side walls were only needed for about 300 feet, and the average cost per lineal foot, including inspection, was $11.97. The customary iron penstock gate was built into the sewer just above the bell-mouth connection chamber by which it joins the main.

As the territory drained by the sewers which empty into Stony Brook is high land, a large automatic regulating apparatus, similar to the one shown on Plate VII., was built into the intercepting sewer at Ruggles Street, by means of which the flow is partly or wholly cut off during severe and continuous rain-storms. Above the regulator is a three-way bell-mouth chamber (Fig. 10, Plate VIII.), from which radiate three principal branch sewers. The centre or main branch, about $4\frac{1}{2}$ feet in diameter, is 1,700 feet long, and intercepts the sewage formerly discharging into the brook by outlets at Elmwood and Hampshire Streets. This sewer passes twice under the brook, at so low an elevation that it preserves its regular grade and shape. The other two branches are built just large enough to enter, being 2 × 3 feet, egg-shaped, with the smaller end down. These also cross twice under the brook, at Tremont Street and at Ruggles Street. Including the regulating chamber, and all sewers above it, this section of work was built by the day, under the City Superintendent, Mr. H. A. Carson. There were built in all 4,229 lineal feet of sewers, including 415 feet of 15-inch pipe. The average cost per foot of the whole was $14.30. A considerable portion of the 2 × 3 feet sewers was built during the winter of 1880–81. The sewers were from 14 to 19 feet below the street surface, and the excavation was done by tunnelling from pits about 10 feet apart. The outlets of the city sewers being below the level of high tide, in order to prevent back-water reaching the intercepting sewer, it was necessary to build gate-chambers just beyond the points of interception, each chamber containing a double set of tide-gates.

The last of the large intercepting sewers joins the main sewer at its present end at the intersection of Camden Street with Huntington Avenue (Plate V.). It is commonly called the West Side intercepting sewer, and is located in streets bordering the westerly margin of the city proper, and intercepts the sewage which formerly discharged into Charles River. This sewer is about $3\frac{1}{2}$ miles long, and its inclination from end to end is 1 in 2,000.

From the main sewer to Beacon Street, and in that street to Charles Street, a distance of 9,325 feet, the West Side sewer was built by day's labor, at an average cost of $13.35 per lineal foot. This section of work includes, besides the customary man-holes, six common-sewer connections, five small regulators, one side entrance, one penstock, and three flushing-gates. The usual form of this sewer is shown by Fig. 8, Plate VIII. It is egg-shaped, five feet six inches high by four feet nine inches wide. It will be noticed that the usual position given to an egg-shaped sewer is reversed in this case, the larger end of the egg forming the invert. This position was adopted because, while affording convenient head-room, it kept the flow line as low down as was practicable. As the flow in this sewer is always a foot or more deep, the hydraulic mean depth, and consequently the velocity of flow, is greater than it would have been had the smaller end of the sewer been below.

A case of slight injury to this sewer may be worth noticing. When the sewer was built on the line of Falmouth Street that street had not yet been filled and graded, and the mud and peat, which underlay the marsh surface in that locality, sometimes extended down below the top of the sewer. About a year afterwards the street was graded with gravel about seven feet high above the original surface of the marsh over the sewer. One side of the street was filled before the other, and the unequal pressure which resulted was transmitted to the sewer, and caused its arch to bulge, as shown by Fig. 12. Fortunately the amount of distortion was not sufficient to endanger the sewer's stability, and the crack was pointed with Portland cement.

In Hereford Street, for a distance of 282 feet, the sewer location passed under a freight-yard of the Boston & Albany Railroad, in which were about 20 lines of track. Piles were driven and stringers placed to support these tracks, and nearly all of the sewer building operations were carried on beneath the surface of the ground, so that the traffic of the railroad was not interfered with. At this point, and beyond the railroad location for a total length of about 800 feet in Hereford Street, a common sewer was built in the same trench, directly above the intercepting sewer. This was done by an arrangement with the City Sewer Department, which designed and paid for the upper sewer. A cross-section of the two sewers, showing their arrangement, is shown by Fig. 9.

In Beacon Street, for a distance of 590 feet in the vicinity of Exeter Street, 22 old stone walls, from five to twelve feet thick, were encountered and had to be cut through. These walls constituted the sluice-way of the old mill-dam, and their removal caused considerable delay. The cost of excavation per lineal foot of trench, 20 feet deep in this street, varied from $3.94 to $14.49. The section from Camden to Charles Street was built in 1878. During a portion of the season work was carried on day and night at two different points. The largest number of men and boys employed at any one time was 369. The rate of progress varied greatly; where no special obstacles were met, 108 feet of completed sewer was built each 24 hours.

On Beacon Street the large common sewers in Hereford, Fairfield, Dartmouth, and Berkeley Streets are intercepted. The sewage from each of these sewers passes to the intercepting sewer through a chamber in which is a small automatic regulating apparatus, similar to the one shown on Plate VIII., so adjusted as to cut off the flow whenever the water in the intercepting sewer exceeds an established depth. The sewers just mentioned are too low to pass over the intercepting sewer, and a somewhat different method of construction was necessary in connecting them. The arrangement at Berkeley Street is shown by Fig. 13, Plate VIII.

A secondary intercepting sewer was built in Brimmer Street, which collects all of the sewage flowing westward from Beacon Hill, and conveys it to the principal intercepting sewer in Beacon Street. For the sake of economy and simplicity the old outlets of the common sewers in Revere, Pinckney, Mt. Vernon, Chestnut, and Beacon Streets were abandoned, and the total flow from these sewers, including rain, is taken by the new Brimmer-Street sewer, a single storm overflow being provided at Back Street. The construction of the Brimmer-Street system involved the building of 1,456.5 feet of oval brick sewers, varying from 2 × 3 feet to 3 × 4 feet 6 inches in diameter; also the rebuilding of about 556 feet of common sewers, which were found to be too low or otherwise defective. The flow from the Brimmer-Street sewer into the intercepting sewer in

Beacon Street is regulated in the same manner as that from the ordinary city sewers.

A little beyond Brimmer Street a large common sewer, which comes from the south across the Public Garden, is intercepted. This drains what is called the Church-Street district, comprising low territory, in which are many cellars which used often to be inundated. Sewage from this sewer, therefore, is taken directly into the intercepting sewer without the intervention of any regulating apparatus.

On Charles Street, from Beacon to Cambridge Street, a distance of 1,832 feet, the sewer was built by contract. It is egg-shaped, 4 × 4.5 feet in diameter (Figs. 6 and 7), and cost $10.10 per lineal foot. This was the only section of the West Side sewer which was built by contract. In excavating the trench many of the hollow-log water-pipes of the old Jamaica Pond Aqueduct Company were found in a perfect state of preservation. A house-drain was found which the drain-layer had connected with one of these water-pipes, although the street sewer was but a few feet distant. The log had but three inches' bore, and, of course, led to no outlet.

At the intersection of Cambridge and Charles Streets a large automatic regulating apparatus, similar to the one shown on Plate VII., was built into the sewer, to control the flow from above. The excavation in which the chamber for this apparatus was built was 30 feet square; but, by flooring over the top of the excavation, and supporting the various lines of street-railway tracks at that place, travel was not impeded, all building operations being carried on below the surface of the street.

From Cambridge to Leverett Street, a distance of 2,150 feet, the intercepting sewer is oval, four feet six inches by three feet in diameter. It is of brick-work, eight inches thick, and usually required a timber cradle-support. The work on this section presented the usual difficulties met with in excavating through filled land, in the way of old obstructions and the free access of tide-water. By a rather curious coincidence, for a distance of about 500 feet, the remains of an old wharf or bulkhead were found, with longitudinal rows of piles within the trench in such positions that, by cutting them off at the proper elevation, they served as a support for the sewer, in the place of new piles which would otherwise have been necessary. Seven hundred and one feet, in all of the Fruit-Street and Livingston-Street sewers, which were too low to be intercepted, were replaced by 2 × 3 feet oval brick sewers. The private sewer from the Massachusetts General Hospital was also too low to be intercepted. This was found to be a rectangular wooden scow, 2.5 × 2.5 feet in diameter, with its bottom at low-tide level. The Trustees of the hospital themselves replaced it with a 10-inch drain-pipe at a higher elevation.

From Charles Street to its upper end at Prince Street, a distance of 3,571 feet, the West Side sewer maintained, with rare exceptions, an even size, of three feet wide and four feet six inches high. The arch consisted of eight inches of brick, and the invert was generally made with four inches of brick, resting on a timber cradle, also four inches thick. The common sewer in Lowell Street, which was a large, flat-bottomed wooden scow, was too low to be intercepted. It was accordingly abandoned, and all branch sewers and house-drains were connected directly with the intercepting sewer. To facilitate making these connections the intercepting sewer was located exactly on the line of the old sewer. The top planks of the latter were removed, but its side planks were retained, and the new sewer, with its width reduced to two feet eight inches, was built between them. The flow of sewage was maintained during the construction through channels above the floor of the old sewer and below the bottom of the new one, which was supported on timber saddles (Fig. 14, Plate VIII.).

Causeway Street is one of the most crowded thoroughfares of the city. It contains two lines of track for horse-cars and one for freight-cars. On its north-westerly side are the depots of three railroads, with no outlet for their passengers and freight except into this street. The tracks of another railroad cross the street. The territory traversed by the street is all made land, consisting of loose materials filled upon a mud bottom.

It was with some apprehension of trouble that work was begun on this section. The most difficult feature of the work was so to conduct it that travel should not be seriously impeded.

Owing to the skill and care of the superintendent and his subordinates, and to the appliances used for handling the earth and other material, the sewer in this street was built within four months, without closing any portion of the street to travel, and with the minimum of inconvenience to the public. At street-crossings and entrances to railroad-yards work was carried on below timber platforms, or bridges, without encroaching upon the street surface. In crossing the Boston and Maine Railroad tracks, the excavating apparatus, with its steam-engine, was so elevated as to leave head-room for the passage of trains. Plate IX. is from a photograph taken at this point.

As a precaution, where the foundation seemed insecure, the vertical diameter of the sewer was increased by six inches, so that, should slight unequal settlements occur, the invert may be brought to its true grade without lessening the desired size of the sewer. For about 76 feet, to avoid interfering with the street surface, the intercepting sewer was built entirely within an abandoned common sewer (Fig. 15, Plate VIII.). At the upper end of the intercepting sewer, at Prince street, the grade of the invert is about four feet above mean low water, which is the highest elevation of any portion of the Main Drainage System. At this point a direct connection with the harbor has been made, which is closed under ordinary circumstances by a three feet square penstock gate. By opening this gate at the time of high tide the sewer can be thoroughly flushed.

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Building the Intercepting Sewer in Causeway Street.

CHAPTER VII.

PUMPING—STATION.

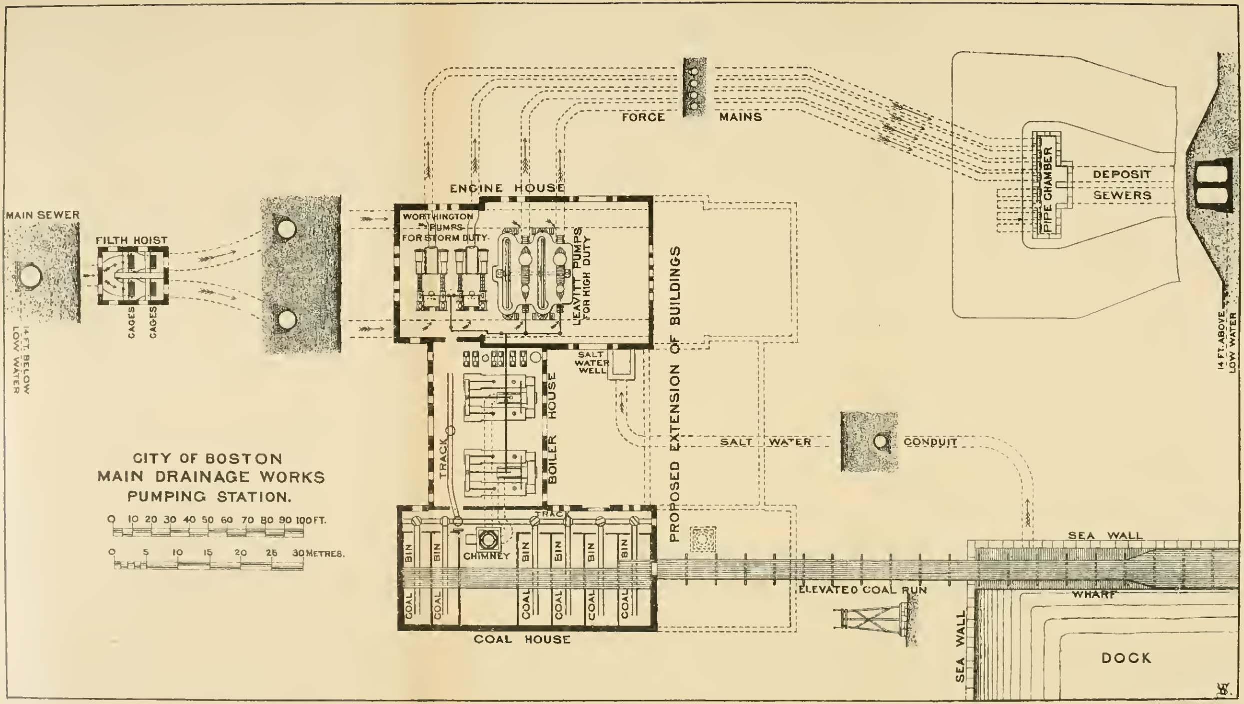
As before stated, and as shown by the plan (Plate V.), the Main Drainage Pumping-Station is situated at Old Harbor Point, on the sea-coast in Dorchester, about a mile from any dwelling. In flowing by gravitation to this point the sewage has descended, so that it is from 11 to 14 feet below the elevation of low tide. To reach its final destination it must flow about 2½ miles further, to Moon Island, and be high enough, after arriving at the storage reservoir on the island, to be let out into the harbor at the time of high water. That it may do this it must first be raised by an average lift of 35 feet.

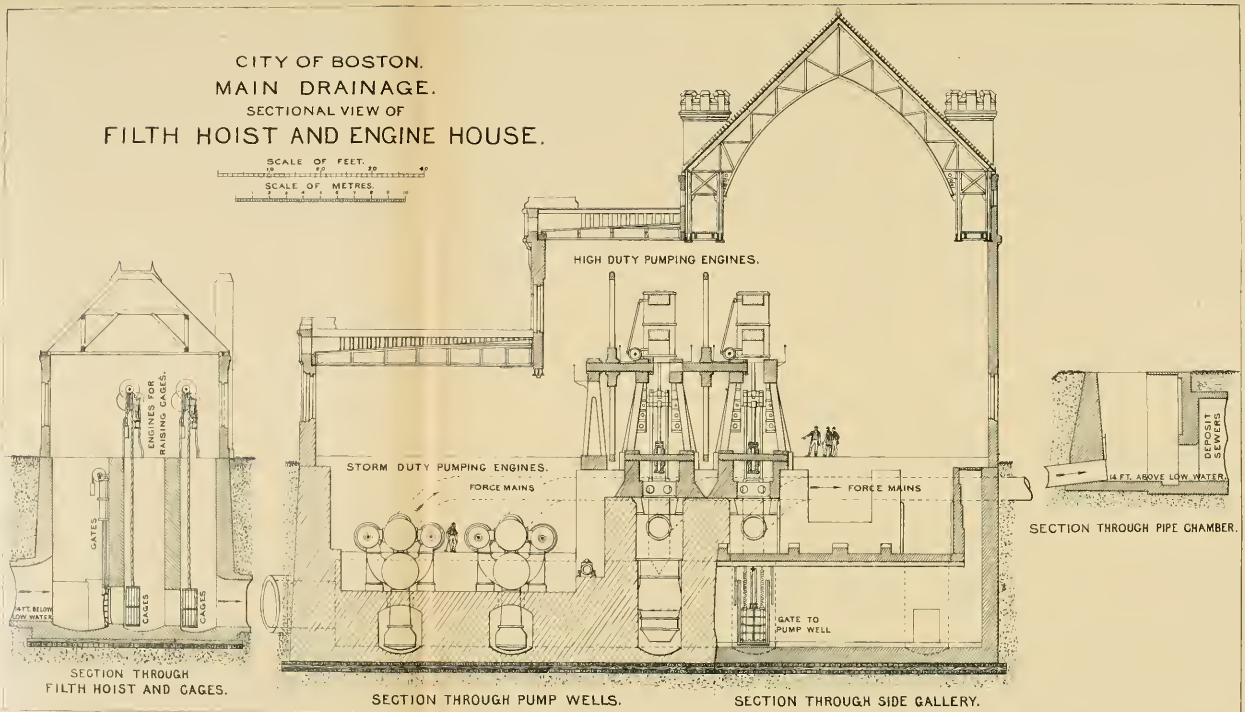
The essential parts of the pumping-station are: a filth-hoist (so called), where the sewage passes through screens to remove solid matters which might clog the pumps; pump-wells, into one or more of which the sewage can be turned; pumping-engines to raise the sewage; an engine-house to protect the engines; a boiler-house, containing boilers to furnish steam-power; a coal-house to store a supply of coal; and a dock and wharf, where vessels bringing coal can be unloaded. The position and arrangement of these principal structures and apparatus are shown on Plate X.

The filth-hoist is a solid masonry structure, extending from the surface of the ground down to below the main sewer. Its inside dimensions are 25 × 32 feet, and its exterior walls are from 4 to 5 feet thick, founded upon two courses of 10-inch timber. In excavating for building the filth-hoist, the ground, which consisted of wet sand, was held by round wooden curbs. The total depth of excavation was 35 feet, and the upper 12 feet were dug without bracing to natural slopes. Below this three tiers of 4-inch sheet planks, each 10 feet long, were driven, and were braced by circular ribs. The three curbs were 71.61 and 57 feet in diameter, respectively, and by this method of bracing an unobstructed space was secured for building the masonry.

As will be seen by referring to Plates X. and XI., the main sewer passes through the westerly foundation wall of the filth-hoist. At this point the sewer has granite voussoirs cut to form a bell-shaped opening. Facing the sewer opening are two gate openings, protected by iron penstock gates, 7 × 6.5 feet each, through one or both of which the sewage flows. These gates are counterbalanced and are moved by hydraulic pressure derived from a city water-pipe. The pressure is sufficient to move them freely; but to start them when down, with a head of water against them, a hydraulic force-pump is added, by means of which the initial pressure can be increased to any extent required. Beyond the gates the structure is divided longitudinally by a brick partition wall into two parts, in each of which are chambers containing two independent cages, or screens, one before the other. The cages are rectangular in shape, 7 feet 8 inches high, 7 feet $3\frac{1}{2}$ inches wide, and 3 feet $4\frac{1}{4}$ inches deep. They are shown in detail by Fig. 4, on Plate XIV. Their backs, sides, and tops are formed of $\frac{3}{4}$-inch round iron rods, with 1-inch spaces between them. The cages are counterbalanced, and are raised and lowered by four small steam-engines. The steam for these engines, as well as for heating purposes, is brought underground from the boiler-house. The superstructure of the filth-hoist is 30 × 37 feet outside dimensions, and is built of quarry-faced granite dimension-stones, lined inside with brick. A view of the outside of this building is shown at the left side of Plate XVII. Plate XII. is from a photograph taken inside of the filth-hoist when one pair of cages was raised. It gives a general idea of the arrangement of the hoisting machinery.

After passing through the cages the sewage is conveyed by one or both of two sewers, nine feet in diameter each, to galleries on either side of the engine-house substructure, from which galleries it can be admitted through gate openings to one or more pump-wells, situated between the galleries. The bottom of the pump-wells is 19.5 feet below low-tide level and 36.5


MAIN SEWER
14 FT. BELOW LOW WATER
FILTH HOIST
CAGES
CAGES
ENGINE HOUSE
WORTHINGTON PUMPS FOR STORM DUTY
LEAVITT PUMPS FOR HIGH DUTY
FORCE MAINS
PIPE CHAMBER
DEPOSIT SEWERS
14 FT. ABOVE LOW WATER
PROPOSED EXTENSION OF BUILDINGS
SALT WATER WELL
BOILER HOUSE
TRACK
SALT WATER CONDUIT
CHIMNEY
BIN
COAL
COAL HOUSE
ELEVATED COAL RUN
SEA WALL
WHARF
DOCK
CITY OF BOSTON
MAIN DRAINAGE WORKS
PUMPING STATION.
0 10 20 30 40 50 60 70 80 90 100 FT.
0 5 10 15 20 25 30 METRES.



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feet below the surface of the ground. From the wells the sewage is raised by the pumps to its required elevation.

The complete design of the pumping-station, as indicated on Plate X., consists of an engine-house, two boiler-houses, and a coal-house, so arranged as to include a court-yard. The buildings are to be of dimensions suitable for containing eight pumping-engines with their boilers and other appurtenances. Only the portions of these buildings shown on the plan by full lines are at present constructed or needed.

The foundation walls of the engine-house aggregate about 350 feet in length. They are 37.5 feet in height and nine feet thick at the bottom, where they rest on a timber platform, 24 inches thick, which also extends under the whole building, and furnishes a foundation course for the piers which support the engines. To build the exterior walls trenches 16 feet wide were first excavated. A core of earth was left inside these trenches until the walls had been erected, when it was removed to make place for the pump-wells and engine foundations. The exterior retaining and foundation walls were built of granite, and, although called rubble masonry, yet, owing to the sizes and shapes of stones used and the care taken in selecting and laying them, the work more nearly resembles a fair quality of roughly coursed block-stone work.

The pump-wells and engine foundations are built chiefly of brick, but contain in addition about 300 dressed granite stones. These stones are used for copings, as bearings for holding-down bolts, for lining gate and other openings, etc., etc. There are nine iron gates, with suitable attachments and shafting, operated by two small steam-engines. Eight of these gates, 4 feet $9\frac{1}{2}$ inches by 6 feet $3\frac{1}{2}$ inches each, control the flow of sewage from the side galleries into the four pump-wells. Another gate, 4×4 feet square, controls the admission of salt water from the salt-water conduit.

This last-mentioned structure, as shown by the plan (Plate X.), is a solid masonry conduit, with its bottom six feet below the elevation of low tide, and connects tide-water at the dock with one of the engine-house galleries. Its office is to conduct salt water to the engine-house for use in the condensers, and also to furnish an additional supply of water to the pumps for flushing or other purposes, whenever the amount of sewage received from the main sewer is insufficient for such purposes.

As has been stated, the sewage is elevated to heights (depending at any time upon the depth of sewage in the reservoir) which average about 35 feet.

As the city sewers receive rain-water, and as it is desired to take as much of this as possible, especially from certain districts, it follows that during short periods of time, when it rains, very much greater pumping capacity is needed than is usually sufficient. There must, therefore, be a pump, or pumps, to run continuously, and others to run only when it rains or thaws.

The chief item of expense in pumping is the cost of fuel. For the sake of economy the pumping-engines for continuous service must do their work with as little consumption of fuel as possible, and to accomplish this an expensive machine can be afforded. For the engines which run only occasionally cheaper machines are more economical, the saving in interest on the first cost more than compensating for the extra fuel consumed by them. The pumping plant of the Boston Main Drainage Works includes two expensive high-duty engines and two cheaper lower-duty engines.

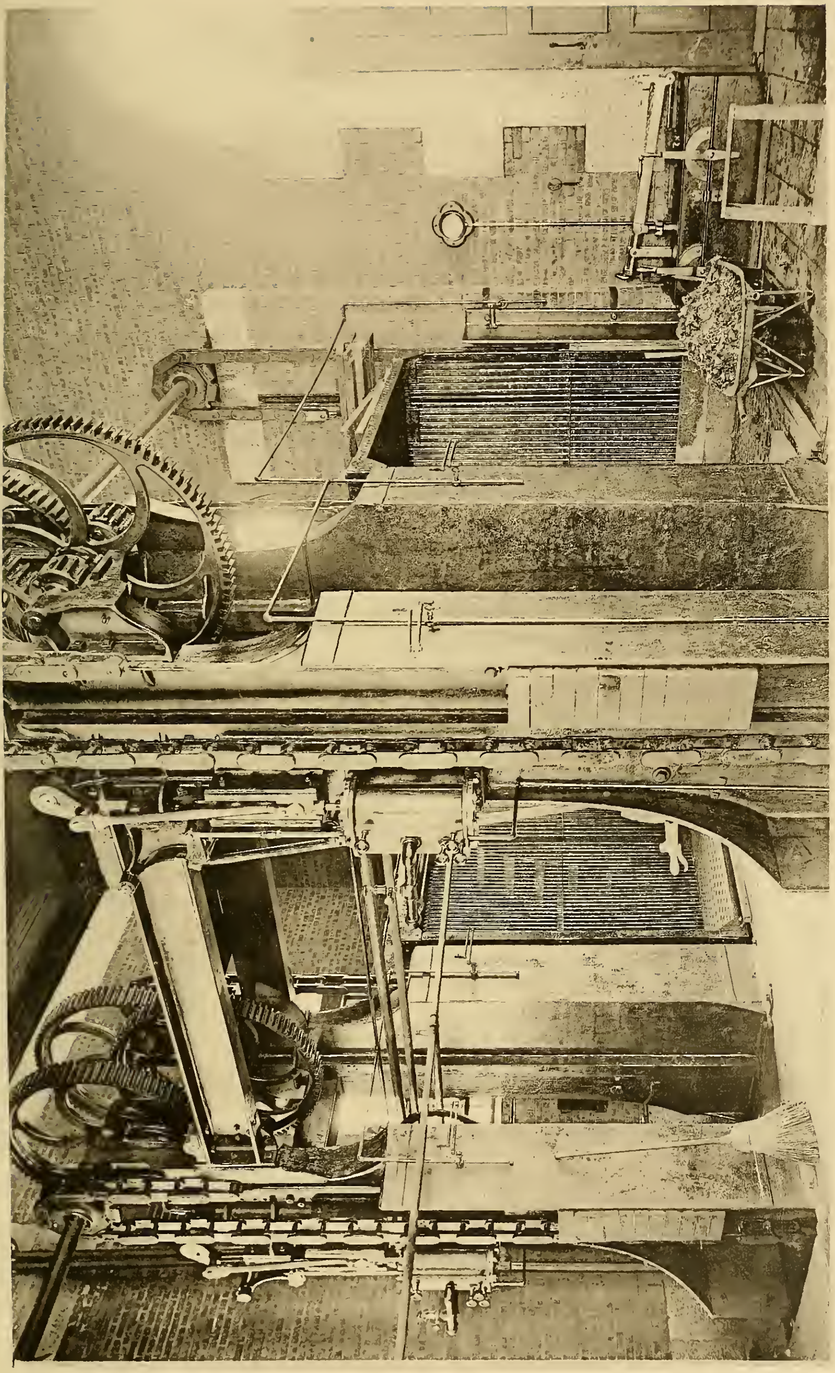
The high-duty engines were designed by Mr. E. D. Leavitt, Jr., on general specifications prepared by the City Engineer, Mr. Davis. They were built by the Quintard Iron Works, of New York, and cost about $115,000 each. A plan and elevation of one of them is given on Plate XIII.

As will be seen, it is a compound beam and fly-wheel engine, working two single-acting plunger-pumps. The steam cylinders are vertical and inverted, their axes coinciding with those of the pumps below them, the pistons of the engines and plungers of the pumps being connected in the same line with the ends of the beam.

In designing these engines particular attention was given to the following conditions: —

First. The distribution of the weight of the engine so as not to produce concentrated pressure on any part of the foundations.

Plate XII.



Interior of Filth-Hoist with one pair of cages raised.

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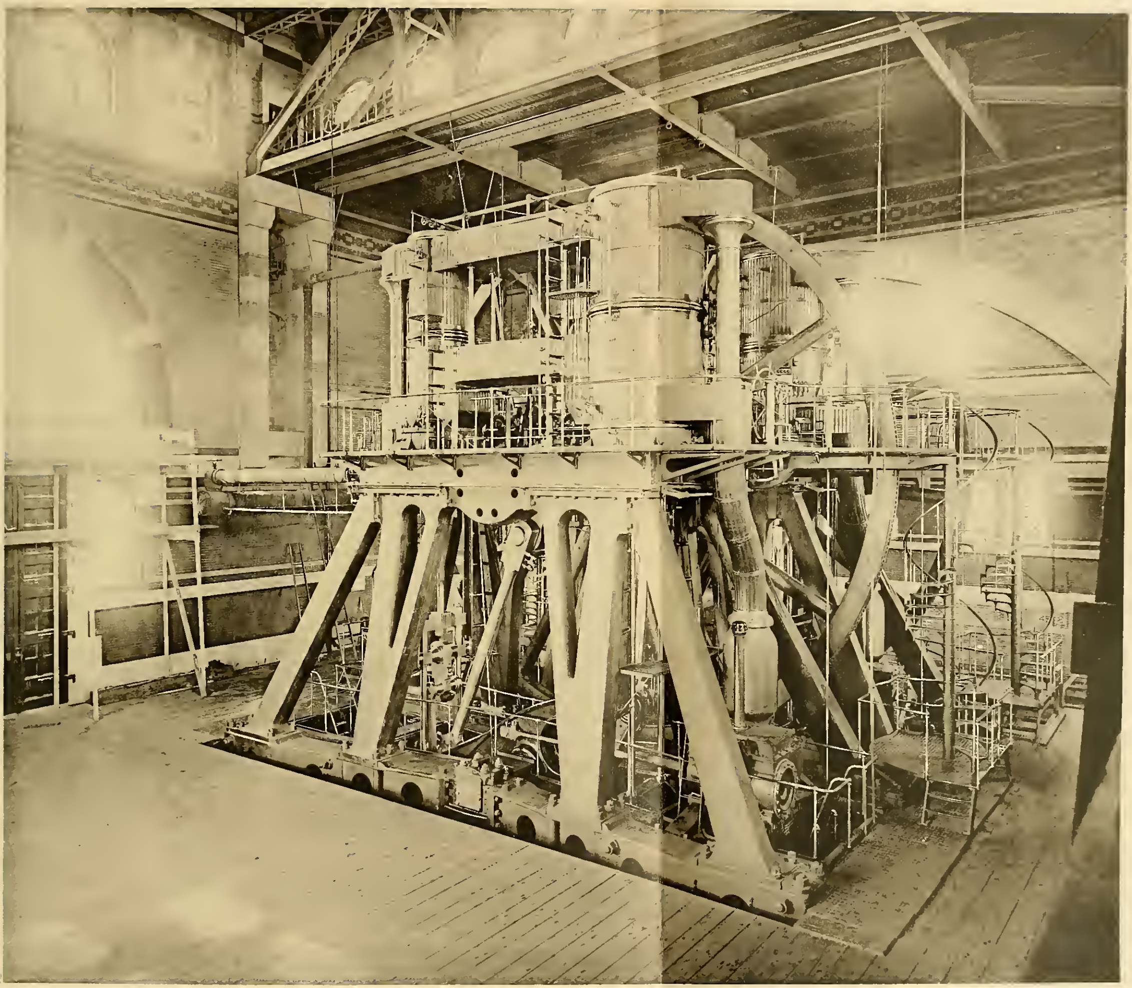

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LEAVITT PUMPING ENGINES.

Second. Great strength in the details and combinations of the parts, to render the liability of breakage a minimum.

Third. A proportion of the wearing surfaces such as will allow of an uninterrupted running for extended periods, with the least wear.

Fourth. Easy accessibility of all the parts for examination, repairs, and renewals.

Fifth. An adaptation of the pumps and their valves to the peculiar duty required of them, *i.e.*, to allow the passage of rags, sticks, and such other small bodies as will not be detained by the filth-hoist; and, in addition, a construction which will admit of the easy removal of an entire pump or any of its parts, without disturbing any important part of an engine.

Sixth. A high degree of economy in the consumption of coal.

The following are a few of the leading dimensions: —

Diameter of high-pressure cylinder, $25\frac{1}{2}$ inches.

Diameter of low-pressure cylinder, 52 inches.

Diameter of plunger, 48 inches.

Stroke, 9 feet.

Distance between centres of cylinders, 15 feet 2 inches.

Radius of beam to end centres, 8 feet 3 inches.

Radius of crank, 4 feet.

Diameter of fly-wheel, 36 feet.

Weight of fly-wheel, 36 tons.

Nominal capacity, 25,000,000 gallons a day.

Speed for capacity, 11 strokes per minute.

Steam at a pressure of about 100 pounds is admitted from the supply-pipe, A (see Plate XIII.), through the side-pipe, B, to the steam-chests of the high-pressure cylinder, C. The distribution of steam is effected by gridiron slide-valves, having a short, horizontal movement imparted by revolving cams, D, fixed on a horizontal shaft, E, running along the bases of the cylinders, and driven by the crank-shaft through suitable gearing, F. The steam is cut off by the further revolution of the cam. The cut-off is adjustable, and controlled by the governor, G.

After expanding to the end of the stroke the steam passes through the exhaust steam-chests to reheaters, H. These are cast-iron boxes, each containing about 750 $\frac{5}{8}$-inch brass tubes, two feet nine inches long. These tubes are filled with high-pressure steam, and in circulating about them the working steam is thoroughly dried.

From the reheaters the steam is admitted to the low-pressure cylinder, I, where further expansion takes place. Thence it passes to the condenser, J, where it is condensed by salt water from a rose jet. K is the air-pump, and L the outboard delivery-pipe.

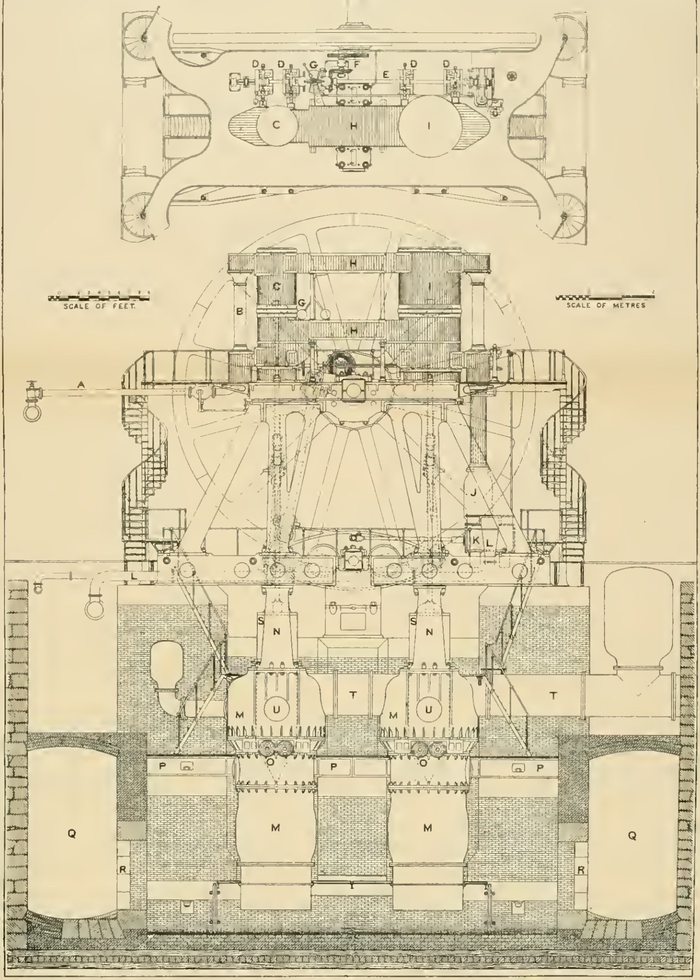
The pumps, M, are hung to heavy girders supporting the engines by cast-iron hangers, N. A part or the whole of the weight of the pumps can also be supported by the wheels, O, resting on very strong cast-iron beams, P, built into the masonry on either side of the pump-wells. By disconnecting their hangers, the pumps, supported entirely by these wheels, can be run back on the beams (which then serve as tracks), and can be hoisted out of the pump-wells without interfering with the fixed parts of the engine.

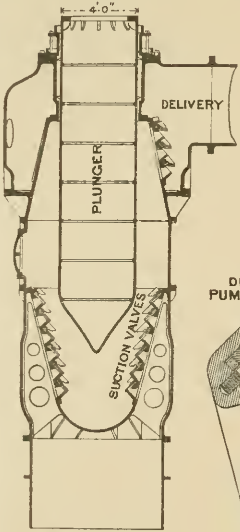
At Q are side galleries, through either of which the sewage reaches the gateways, R, leading into the pump-wells. In front of these gateways are iron gates, not shown on the plate, which admit or exclude the sewage. S S are the plungers. U U are man-holes. T is the force-main. The discharge from one pump passes through the delivery-chamber of the other.

The interior construction of the pump is shown by Fig. 1 on Plate XIV., which is a vertical section through the pump under the high-pressure cylinder. The plunger is represented as just completing its down stroke. The suction-valves (of which there are 36 to each pump) are closed, and the delivery-valves (27 in number) are wide open, to permit the discharge of the sewage displaced by the plunger. In the other pump, at the same moment, the plunger would be completing its upward stroke, and the action of the valves would be reversed.

The valves are of somewhat novel construction, and are shown by a section of a portion of one of the valve-plates, and the whole of one valve (Plate XIV., Fig. 2). As will be seen, they are simply rubber flaps, $\frac{3}{4}$-inch thick, with wrought-iron

BOSTON MAIN DRAINAGE, LEAVITT PUMPING-ENGINE.





LEAVITT PUMP

Fig. 1

DETAIL OF PUMP VALVES

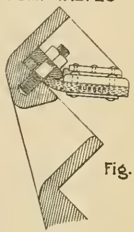
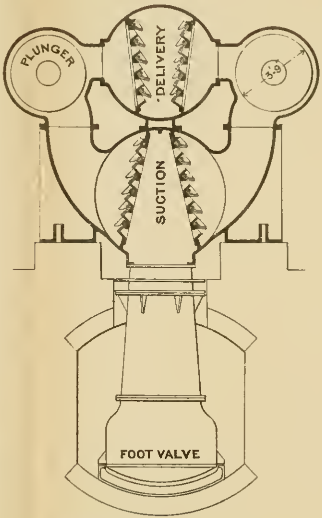
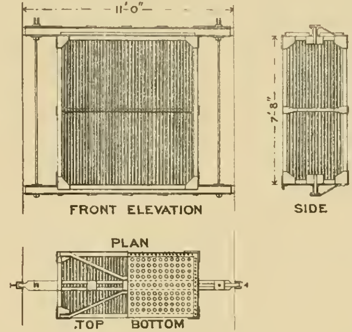


Fig. 2



WORTHINGTON PUMP

Fig. 3



FILTH CAGES

Fig. 4

CITY OF BOSTON,

MAIN DRAINAGE.

PUMPS AND FILTH CAGES.

backs and washer plates, the rubber faces bearing on cast-iron seats inclined at an angle of 45°. The valves form their own hinges, and open against guards or stops faced with leather. The clear opening is $4\frac{1}{2} \times 13\frac{1}{2}$ inches. Pieces of board 10 inches wide and 24 inches long have passed through these valves.

The ordinary working duty of these engines is nearly or quite 100,000,000 foot-pounds to each 100 pounds of coal.[1]

The two pumping-engines for storm service were built at the Hydraulic Works, Brooklyn, L.I., by the firm of Henry R. Worthington, of New York, from their own designs, and cost $45,000 each.

They are of the Worthington duplex, compound, condensing type. Each machine consists in reality of two distinct compound engines coupled together, each engine working a double-acting plunger-pump. The capacity of each double engine is 25,000,000 gallons of sewage a day raised against a total head of 43 feet. This requires about twelve double strokes a minute and a piston speed of about 115 feet per minute.

Steam at from 40 to 50 pounds is carried full pressure through the stroke of each high-pressure cylinder. Thence it passes through reheaters to the adjoining low-pressure or expansion cylinders, and is expanded during the reverse stroke. It is then admitted to the condenser and condensed by a jet of salt water. The steam cylinders are 21 and 36 inches in diameter respectively. They are steam-jacketed all over and suitably coated and lagged. The stroke is four feet.

The steam-valves are moved by a novel and ingenious contrivance, called by the makers "the hydraulic link." Each engine has two small vertical cylinders, in which are plungers worked from the air-pump bell-crank. These plungers force water forward and backward through pipes leading to a cylinder in front of the high-pressure steam-chest. In this

[1] Two duty trials, of 24 hours' duration each, have been made recently of one of the Leavitt pumping-engines. These tests were very carefully conducted, and all fuel burned under the boiler was charged, no deductions being made for ashes and clinkers. In the first trial steam required for the feed-pump was supplied from a separate boiler. Making no deduction for this, the duty developed was a little over 125,000,000 foot-pounds for each 100 pounds of coal. In the second trial the same boiler supplied steam for the pumping-engine and the feed-pump, and the duty developed was about 122,000,000 foot-pounds.

cylinder is a piston connected with the main valve-stem of the engine, and the pressure imparted by the water alternately to opposite sides of the piston moves the valve-stem and effects the steam distribution.

There are two pumps to each machine. Fig. 3, Plate XIV., is a section through the pumps of one engine. Each pump is double-acting, being divided transversely in the middle by a ring which packs the plunger. The plunger is hollow, 45 inches in diameter, and has a 4-foot stroke. It displaces its bulk of sewage at each stroke in either direction. The positions of the valves, suction, and delivery chambers are indicated by the section. The valves are similar to those of the Leavitt engines.

The engines and pumps are compact, and very conveniently arranged for inspection of all their parts. A fair idea of their appearance can be obtained from Plate XV., which is a photograph taken inside the engine-house. The guaranteed duty of these engines is 60,000,000 pounds of sewage raised 1 foot high by the consumption of 100 pounds of coal.

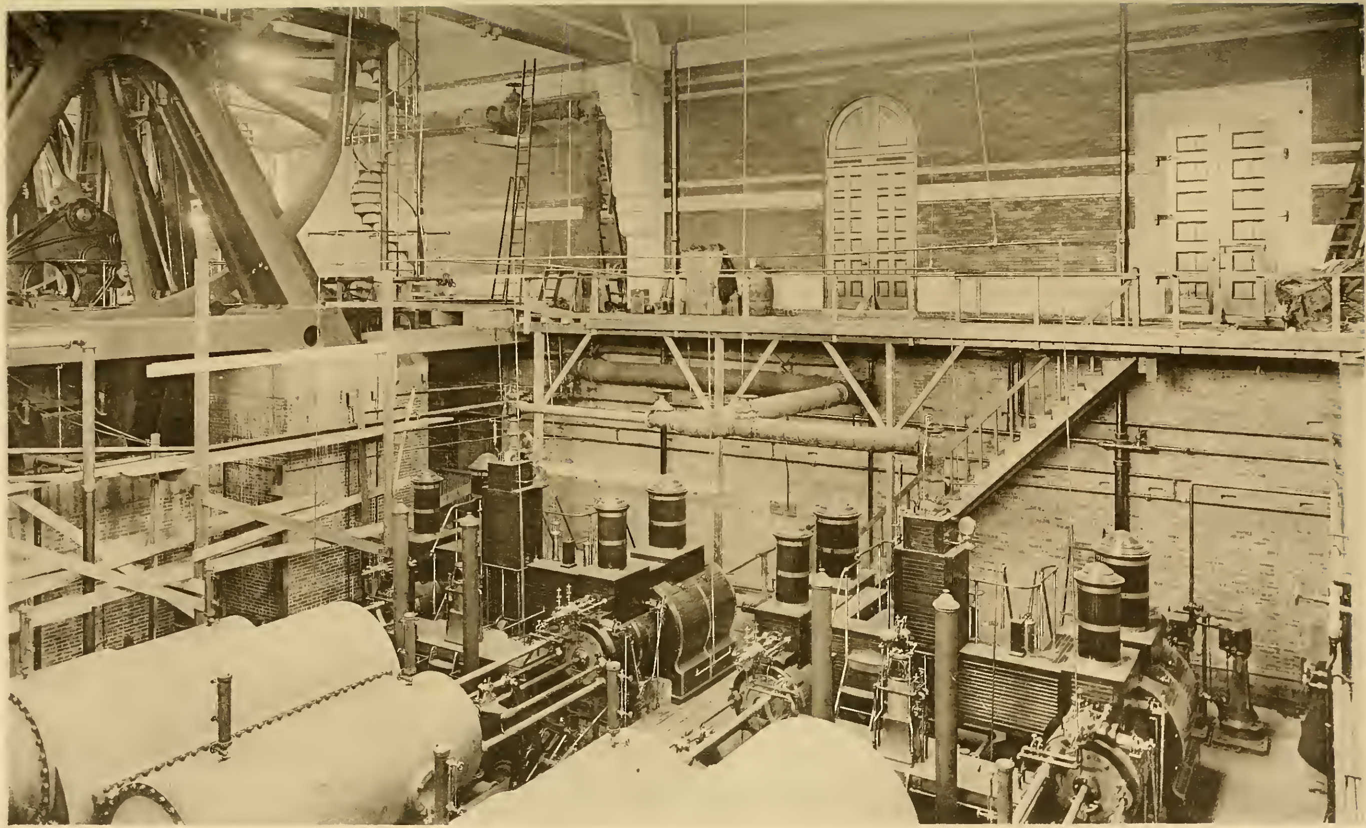
To supply steam for the four engines there are four boilers, of a nominal capacity of 250 horse-power each. They were built by Kendall & Roberts, of Cambridge, Mass., and cost about $9,500 each.

The boilers are of the horizontal fire-box, tubular form, and are made of homogeneous steel having a tensile strength of not less than 60,000 pounds per square inch, an elastic limit of 37,000 pounds, and an elongation of 30 per cent. The shell is $\frac{7}{16}$ inch, and the tube-sheets are $\frac{1}{2}$ inch thick. The length over all is 39 feet 10 inches. There are 132 tubes, 3-inch internal diameter, 15 feet long.

Each boiler has two fire-boxes, $3\frac{1}{2}$ feet wide, 5 feet high, and 11 feet long. At the ends of the fire-boxes is a combustion chamber four feet long.

The smoke-flues return into chambers containing flue-heaters, composed of 80 seamless brass tubes, $2\frac{1}{2}$ inches in diameter and 15 feet long. The heaters are on a level with the boiler-house floor, and can be run out from their chambers for cleaning or repairs. From the heaters the smoke passes by brick flues under the floor to the chimney.

PLATE XV.



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Interior of Engine-House, showing Worthington Pumping Engines.

PLATE XVII.

Main Drainage Pumping Station. Side View.

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The chimney has a circular flue, 66 inches internal diameter and 140 feet high.

Among the minor engines and pumps appertaining to the pumping-station are four engines for raising and lowering the filth-cages; two engines for moving the gates in the engine-house galleries; two pair of double-acting steam-pumps for feeding the boilers; two double-acting steam-pumps for supplying salt water to the condensers; one large steam-pump for emptying the pump-wells and galleries in the engine-house.

The buildings are warmed by a system of steam-pipes and radiators, and are lighted by gas made on the premises from gasoline.

The coal-house is 129 × 59.5 feet in internal dimensions. It contains six coal-bins, or pockets, with a combined capacity of about 2,500 tons of coal. These bins are 23 feet high, and are built with solid walls formed of 2 × 6 inch spruce lumber, planed to an even thickness, and spiked flatwise on each other, — a method of construction similar to that used in building grain elevators. The coal-house floor is made of Portland cement concrete. Iron cars are used for bringing coal from the bins to the boilers, and suitable tracks, turn-tables, and scales are provided.

To furnish access to the pumping-station for colliers and other vessels, a channel one-half of a mile long was dredged out to the ship-channel in Dorchester Bay; 380 feet of dock-wall and a wharf 280 feet long were constructed. To facilitate the unloading of coal a coal-run, supported on a trestle 27 feet high, connects the wharf with the coal-house, and extends over the tops of the bins within the house.

Above their foundations all buildings at the pumping-station were designed and built by the City Architect's Department. A front view of the main building is given by Plate XVI. (frontispiece), and a side view by Plate XVII. This building cost about $300,000.

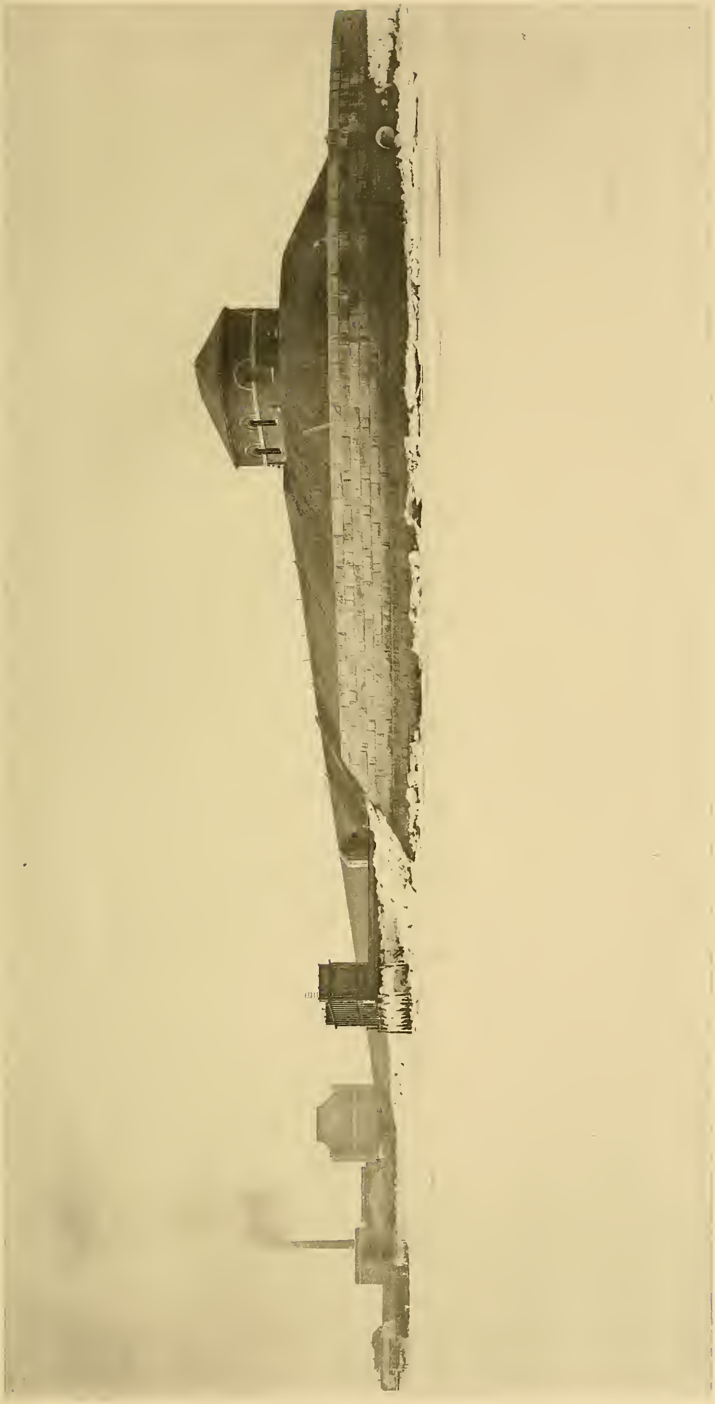
CHAPTER VIII.

OUTFALL SEWER.

The sewage is pumped through 48-inch iron force mains (Plates X. and XI.) into what is called the pipe-chamber. At this point the sewage reaches its greatest elevation, and is high enough to flow into the reservoir at Moon Island. The pipe-chamber is a granite masonry structure, 51 feet long inside, resting on a foundation bed of concrete, 24 inches thick. The walls are 21 feet high, from 4 to 7.5 feet thick, and contain more than 100 dressed stones. The force mains from the four pumps already provided pass through the westerly wall of the pipe-chamber, and four more short sections of 48-inch pipes are also built into that wall, to connect finally with the four additional pumps, which it is expected may be needed in the future.

From the pipe-chamber the sewage passes into what are called the deposit sewers, and through them flows nearly a quarter of a mile to the west shaft of the tunnel under Dorchester Bay. These sewers are supported and protected by a gravel pier or embankment, built from the original shore line at the engine-house out to, and including, the tunnel shaft. Plate XVIII. gives a general view of this pier from its outer end. The picture is a reproduction of a photograph taken during the winter when the bay was frozen over. A cross-section of this pier is shown by Fig. 5, Plate XIX. It is built of gravel, which was mostly dredged from the harbor. On its northerly or most exposed side the pier is protected by a riprap embankment, ballasted with broken stones and oyster-shells. The southerly slope is ballasted and paved with stone, and the easterly end of the pier is protected by a retaining-wall (Fig. 4) of cut-stone masonry, laid in mortar and backed with concrete, the whole resting on a pile foundation. In all there were used in building this pier about 41,000 tons

PLATE XVIII.



View of Old Harbor Pier and Pumping Station, in Winter.

HELIOTYPE PRINTING CO., BOSTON

of riprap, 16,000 yards of ballast, 120,000 yards of gravel, 600 yards of dimension stone, and 650 piles. The pier was built by contract, and its total cost, excluding that of the sewer, was $142,064.97.

The general character of the deposit sewers is shown by Fig. 7. As will be seen, they consist of a monolithic structure of concrete, forming two conduits, each 16 feet high and 8 feet wide. This height is necessary to accommodate the daily variations in the elevations of the surface of the sewage due to filling and emptying of the reservoir at Moon Island. The sewers are dammed at their lower ends to maintain a depth of from 8 to 10 feet, in order that the velocity of flow through them may be very sluggish, so that any suspended matters may be deposited here before reaching the tunnel. They are provided with gates and grooves for stop-planks, so that the sewage can be turned through either or both sewers, and either can be entirely emptied if necessary.

The whole structure contains about 10 cubic yards of concrete to the lineal foot, or over 12,000 yards in all. The bottom portion up to the straight walls is formed of Rosendale cement, sand, and stone, in the proportion of each, respectively, of 1, 2, and 5. Above this elevation, for the outer side walls, the same proportion is maintained; but the cement used was a mixture of 1 part Portland and 2 parts Rosendale. For the concrete forming the centre wall and top arches only Portland cement was used. The best Rosendale and very fine ground Portland cement were procured for the work. The sand was screened on the spot from the gravel forming the pier, and a portion of the stone was obtained in a like manner. A still larger proportion of the stone came from the tunnel excavation, being brought in lighters from the middle shaft and passed through a stone-crusher. Machine concrete mixers were used, into which the cement, sand, and stones, in proper proportions, were continuously shovelled.

The concrete was rammed thoroughly in 6-inch courses. Long sticks of timber were embedded in each layer of concrete while it was being rammed into place, and were removed after it had set, and before the next layer was added. The spaces occupied by the sticks formed grooves, into which the succeeding layers bonded. In cutting through one side of this structure six months after its completion the whole mass was found to be perfectly homogeneous, and lines of demarcation between the different layers could not be detected.

The bottoms of the sewers are lined with one layer of hard-burned bricks to resist erosion when the sewers are cleaned. The sides are plastered with a $\frac{1}{2}$-inch coat of Portland cement mortar. The arches are of long radius and but 13 inches thick. As they were to be loaded at once, they were tied, as shown, by $1\frac{1}{2}$-inch wrought-iron rods, spaced five feet apart. Brick man-holes were built at intervals of 300 feet.

Comparatively heavy matters, such as gravel and sand, settle almost at once at the west end of the deposit sewer. Lighter matters travel a little further; but only a very light semi-fluid precipitate is ever found at the easterly ends of the sewers, near the shaft.

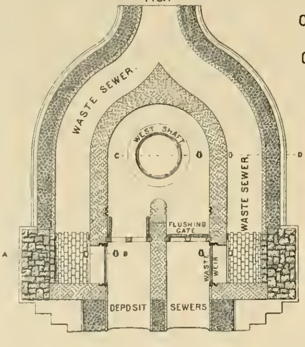
The best way to clean out this deposit was long considered, and the following plan was finally adopted: A large wooden tank was built near the end of the pier, just outside of its southerly slope, about 120 feet distant from the sewers (Figs. 3, 5, and 6, Plate XIX.) It is supported on piles, its floor being three feet above high water and one foot lower than the bottoms of the sewers. One end of this tank is connected with the deposit sewers by two 6-inch iron pipes, the other end is connected with the chamber about the tunnel-shaft by a 12-inch pipe. By means of stock-planks the surface of water is made to stand about three feet higher in the deposit sewers than it does in the shaft-chamber. Circulation is thus established from the deposit sewers through the 6-inch pipes into the tank, and thence through the 12-inch pipe to the shaft, and a part of the sewage goes to the tunnel through this by-pass.

The 6-inch pipes leave the deposit sewers near their bottoms, and the sewage which enters the pipes draws sludge along with it and again deposits it in the still water of the tank. The tank is 10 feet wide, 15 feet high, and 50 feet long, and will hold about 150 yards of sludge. It has on its seaward side three gate-openings, terminating in cast-iron nozzles, 12 inches

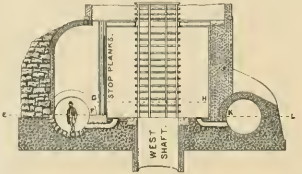
CITY OF BOSTON MAIN DRAINAGE OUTFALL SEWER

SECTIONAL PLAN ON LINES E.F.G.H K.L.

FIG. 1

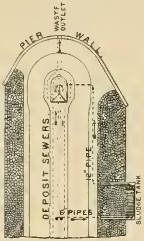


CHAMBER CONNECTING DEPOSIT SEWERS WITH WEST SHAFT OF TUNNEL



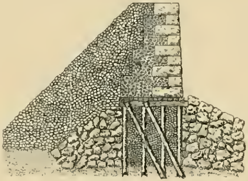
SECTIONAL ELEVATION ON LINES A.B.C.D.

FIG. 2



OLD HARBOR PIER PLAN AT END.

FIG. 3



END WALL OF PIER.

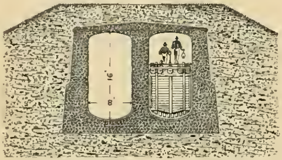
FIG. 4

OLD HARBOR PIER CROSS SECTION.

FIG. 5

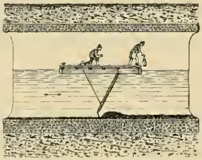
SLUDGE TANK.

FIG. 6



TRANSVERSE SECTION OF DEPOSIT SEWERS AND END VIEW OF SCRAPER.

FIG. 7



LONG. SECTION OF DEPOSIT SEWER SHOWING SCRAPER.

FIG. 8

in diameter. When the tank is full of sludge a scow is laid alongside it, and the nozzles are connected with the interior of the scow by means of canvas tubes. The gates are then opened, and the sludge flows from the tank into the scow.

In order to draw down to the 6-inch pipes the sludge which has been deposited at the upper ends of the deposit sewers scrapers are used. These consist of floating rafts (Figs. 7 and 8, Plate XIX.), made of 12-inch hollow iron tubes, to the bottoms of which are hung wooden aprons, a little less wide than the sewers. The aprons are weighted so that their lower edges, which are provided with broad iron teeth, sink somewhat into the sludge. The current in the sewers carries the whole apparatus down stream, and the sludge is scraped and flushed before it.

The deposit sewers connect with the tunnel shaft at a masonry chamber built about the latter (Figs. 1 and 2, Plate XIX.). At the ends of the sewers are placed gates 7 × 8 feet in size. These gates maintain a depth of eight or more feet in the sewers. They are so arranged that on tripping a latch they can swing open and empty suddenly the liquid contents of the sewers into the tunnel, producing temporarily a strong flushing velocity. Immediately about the shaft is a wrought-iron cage, to prevent any bulky object which may fall into the sewers from reaching the tunnel.

The shaft chamber is encircled by two 6½-feet "waste sewers," into which the deposit sewers can overflow above waste weirs, or with which they can directly connect instead of discharging into the tunnel. The waste sewers unite just east of the shaft-chamber and pass to an outlet built through the sea-wall at the end of the pier. Should the tunnel ever be emptied for inspection sewage can temporarily be pumped into Dorchester Bay through this outlet. Above the shaft chamber is a brick gate-house of ornamental design, built by the City Architect.

The second section of outfall sewer comprises the tunnel under Dorchester Bay. Exploratory borings made on the tunnel line during the preliminary survey showed that the surface of bed rock was but little below the bottom of the harbor, from Squantum to about the middle of the bay. From that point westwardly towards Old Harbor Point the rock dipped rapidly, so that under the pumping-station its surface is 214 feet below the surface of the ground. The surface of the rock is somewhat shaken, and immediately above it is a water-bearing stratum of sand, gravel, and boulders. Above this, clay extends nearly to the harbor bottom, which is composed of a bed of mud of varying thickness.

The clay is of uniform character, and contains occasional veins and pockets of sand. Using reasonable precautions a tunnel could be safely and expeditiously built in it. The pervious stratum over the rock and the demoralized upper portion of the rock itself were not at all favorable for tunnelling operations, and could only have been penetrated with extreme precaution and a considerable chance of failure. The rock itself was well adapted for tunnelling. It consists of a succession of clay-slates and conglomerates, and belongs to the series known as the Roxbury "pudding-stone" beds.

When the trough in which these beds lie was formed they were subjected to great pressures, which crumpled and tilted them, and produced many faults, fissures, and joint planes.

The fissures were filled solidly from below, and few shrinkage seams were found sufficiently open for the passage of water from above. The existence of the joint planes, especially in the clay-slates, greatly facilitated the breaking and removal of the rock.

As at first designed the tunnel was to start from a shaft 100 feet deep at Old Harbor Point and be built in the clay for about 2,100 feet, when it would enter the rock and continue in it to its end, at Squantum. Further consideration of the difficulty and possible danger of passing gradually from soft ground into rock, and of tunnelling for several hundred feet wholly or partly through very wet and loose material, led to locating the west shaft at such a distance from the shore that rock could be reached at a practicable depth and the tunnel could be safely built wholly within it.

The average elevation of the tunnel is 142 feet below low water (Plate XX., Fig. 1). The total length through which the sewage flows is 7,160 feet. Of this distance 149 feet is in the west shaft, 6,088 feet is nearly horizontal between the west and east shafts, and 923 feet is in the inclined portion leading from the bottom of the east shaft to the end of the tunnel, on Squantum Neck.

To facilitate construction there were three working shafts about 3,000 feet apart.

The tunnel was built under a contract which was drawn with great care. The contractor was first to build, in accordance with plans furnished, three timber bulkheads, or piers, to protect the shafts. Inside of these bulkheads he was to sink iron cylinders, constituting the upper portions of the shafts. These cylinders were paid for by the lineal foot, and the contractor was permitted and required to build as much of the shafts as possible in this way, loading and forcing the iron to the greatest attainable depth. Below the cylinders the shafts could be excavated of any desired size and shape. The tunnel, also, could be excavated of any size, provided that both it and the shafts were finally lined with a $7\frac{1}{2}$ feet diameter circular shell of brick work, 12 inches thick, backed with brick or concrete masonry to the sides of the excavation. Bricks and cement were to be purchased from the city at stipulated prices. The completed tunnel was to be paid for at the proposed price per lineal foot.

Great stress was laid upon the precautions to be adopted to prevent delay and damage arising from an influx of water into the shafts. Appliances to control any such influx were to be kept in readiness, and, should these prove insufficient, the plenum process, or use of compressed air within the shafts, was to be resorted to.

The work was let Oct. 29, 1879, and the contractor at once proceeded with the building of the bulkheads. These were alike, and consisted (Fig. 2, Plate XX.) of wooden boxes 20 feet square inside, formed of large oak piles, driven two feet on centres, capped and braced with hard-pine sticks, and tied diagonally at the corners with 2-inch iron bolts. The boxes were lined inside with 4-inch tongued and grooved sheet-piling, and the spaces between the sheet planks and cylinders were filled with puddled clay. The tops of the bulkheads were eight feet above mean high water, and the contract price for them was about $2,500 apiece.

Having completed the bulkheads the cylinders were sunk inside of them. Each cylinder (Plate XX., Fig. 3) consisted of a circular shell of cast-iron, 9.5 feet inside diameter, with $1\frac{3}{4}$ inches thickness of metal. They were cast in sections, five feet long, and united by $1\frac{1}{8}$-inch bolts passing through inside flanges. The abutting ends of the sections were faced, and the bolt-holes, of which there were 30 in each flange, were drilled to a templet, so that the sections were interchangeable. The bottom section of each cylinder had its lower 10 inches chamfered off to a cutting edge. The contract price for furnishing the cylinders, which weighed a ton to the foot, was $88 per lineal foot.

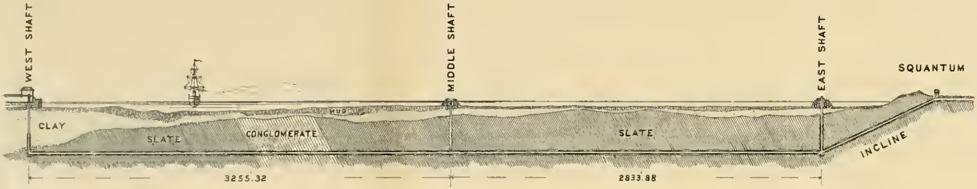
At the east and middle shafts the cylinders were easily forced down to the rock, at depths below the surface of the ground of 21 and 38 feet respectively. It was known that it would be impossible to drive the cylinder at the west shaft down to the rock. By weighting it with about 180 tons of iron dross it was finally forced into the clay to the depth of about 60 feet below the harbor bottom. Below this point a square shaft, 10 feet across, was excavated with great ease in plastic clay, penetrated with occasional veins of fine sand, but yielding little water (Plate XXI., Fig. 1).

The timbering of this shaft was hastily and, as it seemed to the engineers, carelessly done, the timbers being insecurely braced, and cavities being continually left outside of them. The engineer in charge consulted the City Engineer as to the possibility of requiring greater caution in doing this work. It was decided, however, that the spirit of the contract would not permit interference with the contractor's method of building this portion of the shaft.

No difficulty was encountered until the rock was neared, when water, to the amount of 10,000 gallons an hour, broke in from below, and, no provision having been made for its removal, filled the shaft. Pumps were obtained and the shaft emptied, when it was found that the water, following the cavities behind the lining, had softened the clay and loosened the timbering, so that

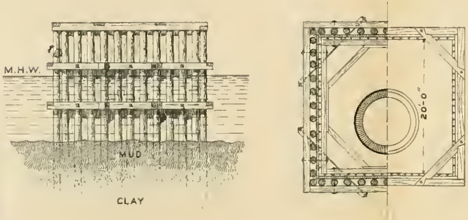
CITY OF BOSTON — MAIN DRAINAGE.

OUTFALL SEWER. DORCHESTER BAY TUNNEL.



LONGITUDINAL SECTION OF TUNNEL

FIG. I.

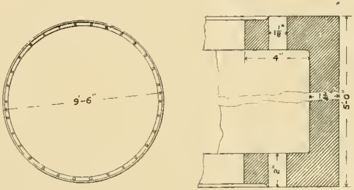


SIDE ELEVATION

HALF SECTION HALF PLAN

BULKHEADS ABOUT SHAFTS

FIG. 2.



PLAN

SECTION

IRON CYLINDERS

FIG. 3.

it was in very bad shape. About 40 feet in length of the shaft had to be retimbered, the old sticks being cut out with chisels.

The work was not accomplished without great difficulty. Although the quantity of water to be dealt with was not great, the cramped dimensions of the shaft afforded little room for the pumps, or opportunity for supporting them. When these gave out, as they occasionally did, the shaft filled with water, causing considerable delay and damage. To counteract a downward pressure exerted by the clay upon the timber lining, a portion of it was suspended by heavy wire cables from the cylinder above. During all these operations the whole shaft, including timbered portion and cylinder, also the surrounding clay and the bulkhead above, were in motion, settling slowly. By the time the shaft had been firmly founded on the rock the pile bulkhead had settled nearly five feet.

After the shafts had been sunk and secured the excavation for the tunnel proper encountered no serious obstacles. The work was carried on at six different headings. From the middle and east shafts work progressed in both directions, and from the west shaft and the upper end of the incline at Squantum single headings were driven.

The incline descends one foot vertical in six feet horizontal. At this point a heading was driven downwards for about 400 feet and then stopped, owing to the difficulty and expense of removing the water which accumulated at its face. At the middle shaft power-drills driven by compressed air were used, and at other points hand drilling was employed.

There was not much difference as to either expense or rapidity in the two methods. By either an advance of four feet was considered a fair day's work. The chief merit of the air-drills seemed to be that they were not demoralized by pay-days, and never struck for higher wages.

Various forms of nitro-glycerine were employed as explosives, and no casualty occurred through its use. The average diameter of the excavation (Plate XXI., Fig. 2) was about 10.2 feet, approximating very well to the 9.5 feet required to receive the final brick lining. The excavated material, amounting to about 25,000 yards in all, was deposited around the shafts, forming small islands. The maximum amount of water leaking into the tunnel at any time was 64,000 gallons an hour.

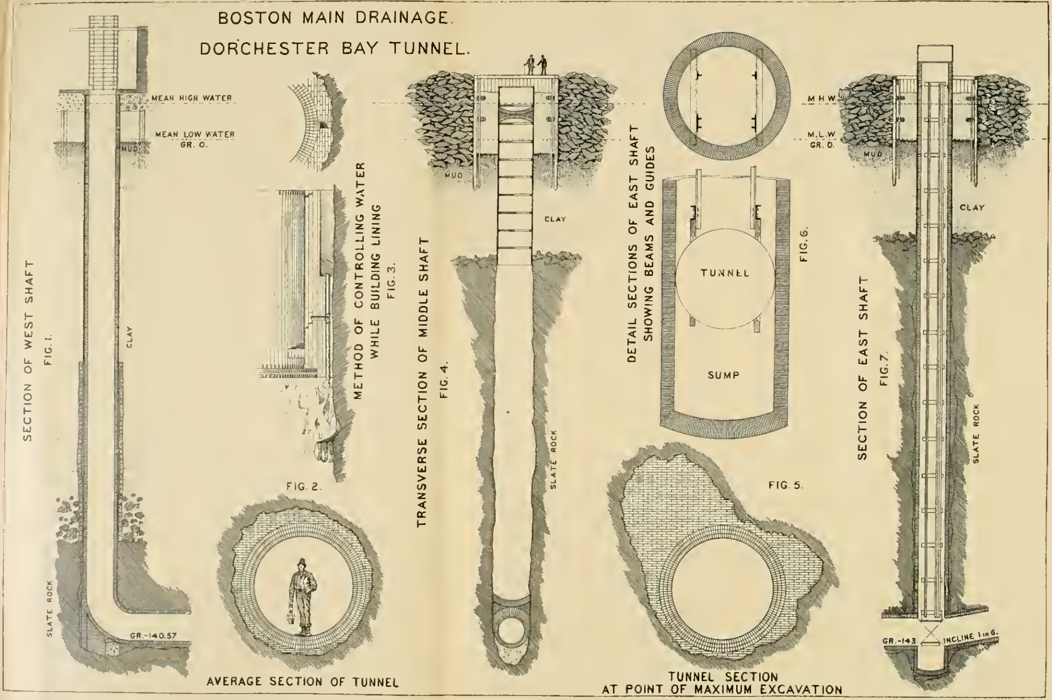
The headings between the east and middle shafts met Jan. 24, 1882, and those between the middle and west shafts met June 22, 1882. Lining the excavation with brick-work began March 10 of the same year. Projecting portions of rock were first trimmed off, so that room for a solid brick lining, 12 inches thick, laid in courses, could always be obtained. Rosendale cement mortar was used, composed of equal parts of cement and sand. All spaces between the coursed lining and the sides of the rock excavation were solidly filled with masonry, principally brick-work. The amount of backing thus required to make solid work averaged about three-fourths of a yard per lineal foot. Fig. 5, Plate XXI., is a section of the tunnel at the point of maximum size where the largest amount of backing was needed. In all, 7,416,000 bricks and 23,377 barrels of cement were used in building the tunnel. About 12 lineal feet of tunnel could be completely lined in 24 hours, at any one point.

In putting in the lining, iron pipes were built into the brick-work (Plate XXI., Fig. 3) wherever necessary to furnish outlets for the water, which would otherwise have washed out the mortar. Some of these pipes were afterwards plugged, but most of them were left open. The pressure of the water when kept from entering the tunnel was about 64 pounds per square inch, and it was not practicable to build brick masonry which should be water-tight under such a pressure. When the tunnel is in use the pressure of the sewage within it is somewhat greater than that of the water outside the lining, so that leakage would be outwards, except that the particles in the sewage will quickly clog any fine holes in the masonry.

Some experiments were made to determine to what extent the porosity of the brick lining could be destroyed by silting from without. An iron pipe extending up the east shaft was connected at its lower end with the pipes built through the brick-work, and water containing clay, cement, and fine sawdust was forced outside the lining.

The finer portions of these materials came through holes and cracks in the joints of the masonry. Fine holes were thus filled

BOSTON MAIN DRAINAGE.
DORCHESTER BAY TUNNEL.



and leakage through them prevented. Holes of apparent size were calked with lead. By these means the leakage into the inclined portion of the tunnel was reduced from 2,200 to 500 gallons an hour. It was not, however, considered practicable, except at considerable expense, thus materially to reduce the leakage; and, in view of its slight importance in respect to the use of the tunnel, the attempt was given up.

The west shaft was lined with brick-work. The middle shaft was abandoned, its only purpose having been to facilitate construction. The arch of the tunnel where it passes under this shaft was made three feet thick, and a counter arch, two feet thick, was built over it to resist upper pressure, in case the tunnel should ever be filled suddenly after having been pumped out for any purpose. The shaft itself was not filled up, but near its top an arch was built to prevent any heavy substance ever falling down it (Plate XXI., Fig. 4).

The east shaft was lined throughout. A large Cornish mining pump has been purchased, and is to be set up at this shaft as soon as certain legal complications affecting the city's right to the location shall have been settled. This pump will have sufficient capacity to empty the tunnel, including the leakage into it, within 48 hours. It is to be set up as a precaution, as it did not seem wise to leave any portion of the work entirely inaccessible. Should the tunnel ever be pumped out at this point it would first be filled with salt water, so that no possible nuisance could be created by the operation.

A sump, or well-hole, seven feet deep, from which to pump, was built under the east shaft (Plate XXI., Figs. 6 and 7). Pairs of cast-iron beams were built into the lining from the bottom of the shaft to its top. To these are bolted two sets of upright iron guides. One set of these will hold in place the rising column of the pump, and the other set will serve for an elevator, to be used in visiting the pump and tunnel.

It was thought that, should deposits occur in the tunnel, they might be removed by passing a ball, somewhat smaller in diameter than the tunnel, through it. To guide this ball past the east shaft, four wooden guides, suitably shaped, were built in place at that point. Appliances for handling such a ball were provided at the two ends of the tunnel.

The tunnel was practically finished July 25, 1883. Its completion required the removal of all elevators, pumps, pipes, etc., used in constructing it and the closing up with masonry of all pump-wells, except the one before referred to, at the east shaft. This work was attended with considerable anxiety, as the pumping capacity of the three shafts was but little more than was necessary to control the leakage of water.

The finishing and removals were successfully accomplished by systematic and careful management. The last shaft to be cleared was the east shaft, and it was necessary to isolate it from the rest of the tunnel by a timber bulkhead, behind which the water entering the tunnel accumulated while the pumps and their appurtenances were being removed. By the time the shaft was clear the tunnel was two-thirds full of water. The bulkhead was so made and fastened in place that on tripping a catch it fell apart into three pieces, which were hauled out by ropes attached to them.

The contract price for the shafts, exclusive of iron, was $86, and for the tunnel $48, per lineal foot. The contractor lost money, and after about two years abandoned his contract, alleging his inability to complete it for the prices therein stipulated. He offered to complete the tunnel for prices about one-half greater than those before agreed upon. Considering that he had the requisite plant on hand, and had acquired valuable experience concerning the character of the work and the best methods of conducting it; and also considering that the bad reputation which the tunnel would have, if abandoned, would probably deter other bidders from making reasonable offers, — it was thought for the best interests of the city to make a second agreement with the same contractor, which was accordingly done. The final total cost of this section of work, including inspection and all incidental expenses, was $658,489.97, amounting to about $92 per lineal foot of tunnel.

The methods of alignment employed by the engineers in immediate charge of the tunnel, while not entirely novel, may be of sufficient interest to be mentioned. The west shaft was out of plumb, so that by dropping plumb-lines a base only 5.7 feet long could be obtained. This by itself would have made accurate alignments tedious. Moreover, each shaft contained about six lines of steam, water, and exhaust pipes, besides guides for its cage. As the shafts were 160 feet deep, were dripping with water, and had currents of air produced by hot-pipes and leakages of steam, it would have been necessary to protect plumb-lines by tubes for the whole depth of the shafts. At the west shaft it would have been impracticable to use such tubes, as they would have been directly in the way of the cage.

On account of the difficulty attending the use of plumb-bobs the line was transferred below by means of a large transit instrument set up at the top of the shaft. The telescope, having been set on line, was directed down the shaft, and a fine string, extending about 100 feet into the tunnel, was ranged in line. The string was illuminated by light reflected from a mirror placed beneath it. Communication between the engineers at the top and at the bottom of the shaft was maintained by the use of hand telephones.

At first the line within the tunnel was produced by means of instruments; but, as the headings advanced, the ventilation became so bad that at times a light distant only 75 feet could not be seen. The line was then produced by stretching a stout linen thread, about 600 feet long, and taking offsets to it. The success attending these methods of alignment was very gratifying, as the headings met without appreciable error.

Should a "high-level" intercepting sewer ever be built to conduct a part of the city's sewage, by gravitation, to Moon Island, it is expected that it will join the present system, on Squantum Neck, at the further end of the tunnel. To provide for such a contingency the present outfall sewer is much increased in size beyond this point, being 11 × 12 feet in dimensions.

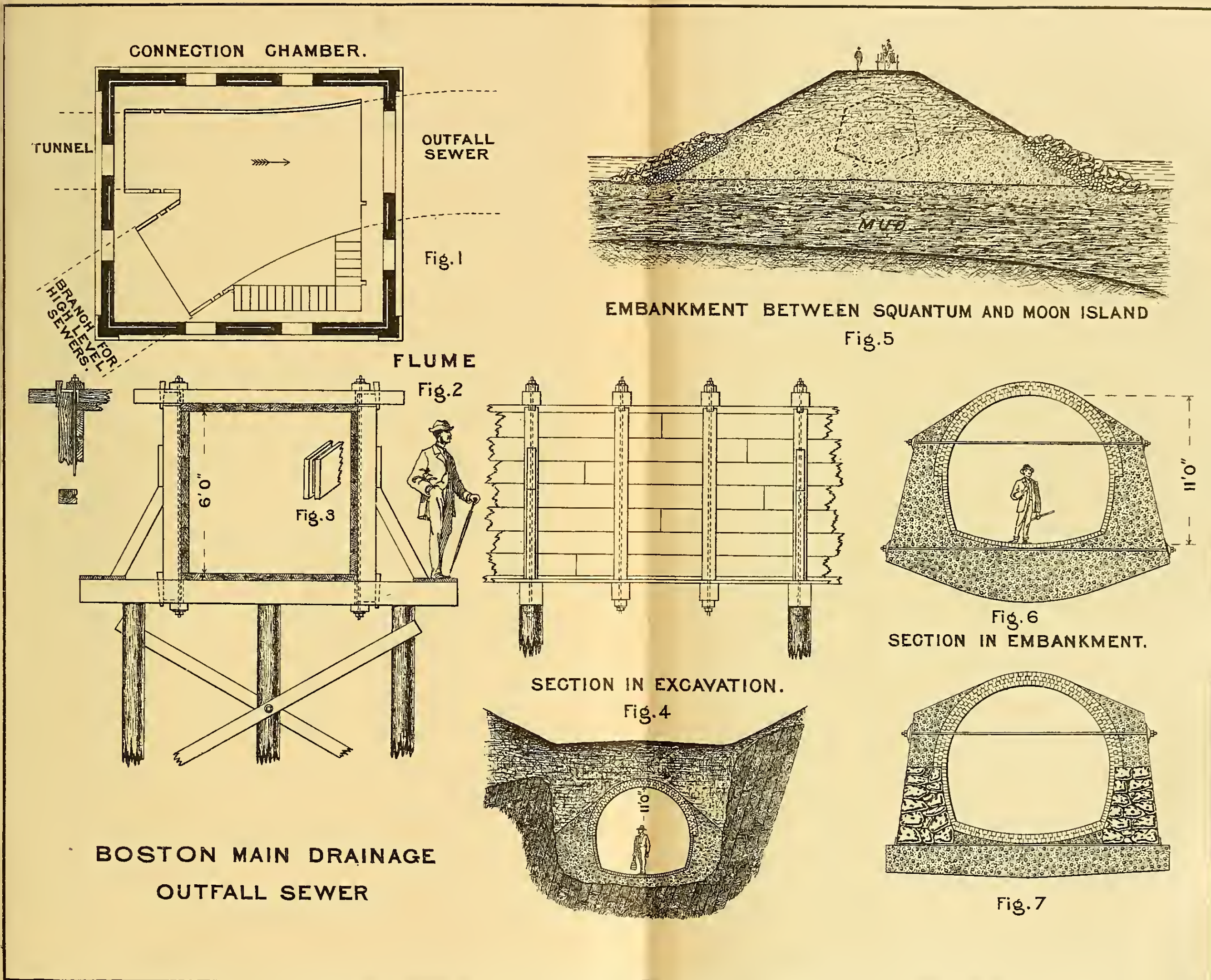
The connection between the tunnel and the outfall sewer beyond is made in an underground chamber (Fig. 1, Plate XXII.). From this chamber, also, branches a short section of sewer with which to connect the future "high-level" system, should it ever be built. The chamber is covered by a substantial brick building, and a flight of stone steps leads to a landing in the sewer below. The floor of the building is supported on iron beams, and can be taken up so that boats can be lowered into the sewer, and a flushing-ball can be taken out. To facilitate these operations the roof was made exceptionally strong, and from it was hung an iron track supporting a traveller and blocks capable of lifting five tons.

As far as the easterly shore of Squantum Neck the outfall sewer (Figs. 4, 6, and 7, Plate XXII.) was built partly in rock excavation and partly in embankment. In the latter case the sewer is tied through its arch by $1\frac{5}{8}$-inch iron rods, 8 feet apart. These are designed to prevent the possibility of distortion, due to movements of the bank below the sewer, or on the side of it. The ties will, doubtless, rust out in time, but not before the need of them is over.

From Squantum to Moon Island an embankment (Plate XXII., Fig. 5) was built. It is a mile long, from 20 to 30 feet high, 20 feet wide on top, and about 120 feet at its base. Up to the established sewer grade the embankment was chiefly built of dredged gravel, and, above that height, of material obtained in excavating for the reservoir on Moon Island. Up to six feet above high water the slopes are protected by ballast and riprap. In all, about 141,000 yards of dredged gravel, 260,000 yards of other earth, 20,000 yards of ballast, and 54,000 tons of riprap were used in building the embankment.

About 4,100 feet in length of the site of the embankment consisted of beds of mud, from 10 to 40 feet deep. It was hoped that the filling would displace this mud and reach hard bottom. It did so at a few points, but not as a rule. As an experiment an attempt was made to assist this action by exploding dynamite cartridges under the embankment. No results of importance were thus obtained; but the experiment demonstrated the resistance of the mud to displacement and the probable future stability of the embankment.

Broad plates, with vertical iron rods fastened to them, were placed near the bottom of the bank on its centre line, and the amount of settlement as filling progressed was noticed. After the bank was completed slight settlements still continued. It


CONNECTION CHAMBER.
TUNNEL
OUTFALL SEWER
Fig. 1
BRANCH FOR HIGH LEVEL SEWERS.
EMBANKMENT BETWEEN SQUANTUM AND MOON ISLAND
Fig. 5
MUD
FLUME
Fig. 2
6'0"
Fig. 3
11'0"
Fig. 6
SECTION IN EMBANKMENT.
SECTION IN EXCAVATION.
Fig. 4
11'0"
Fig. 7
BOSTON MAIN DRAINAGE
OUTFALL SEWER

was, therefore, thought more prudent to postpone building a masonry structure for some years, or until there was assurance that the bank had assumed a condition of permanent stability.

For temporary use, therefore, a wooden flume (Fig. 2, Plate XXII.) was substituted for the masonry sewer at this point. The flume is located outside of the embankment, and 200 feet south of it. It is supported on piles, in bents ten feet apart, generally with three piles to the bent. In all, about 1,300 piles were driven, some of them to a depth of 40 feet.

The flume proper consists of a wooden box, six feet square. Its sides, top, and bottom are formed of Canadian white pine, three inches thick, planed all over. The planks, except a single filling in course on each side, are all of even width, so as to allow breaking joint. They are grooved on each edge, and also on their ends (Fig. 3), for $1\frac{1}{2} \times \frac{3}{4}$-inch tongues. The box is surrounded, at intervals of three feet four inches, by square frames of spruce timber, mortised together and tightened with bolts and wedges.

The pine and spruce were fitted at the mills, so as to go together with the least possible further fitting. As much as 250 feet in length was assembled and spiked in a single day. After completion the whole was given two coats of cheap paint. The total cost of the flume was a little under $10 per lineal foot.

From the further end of the flume the outfall sewer (Fig. 6) extends up to and in front of the storage reservoir.

CHAPTER IX.

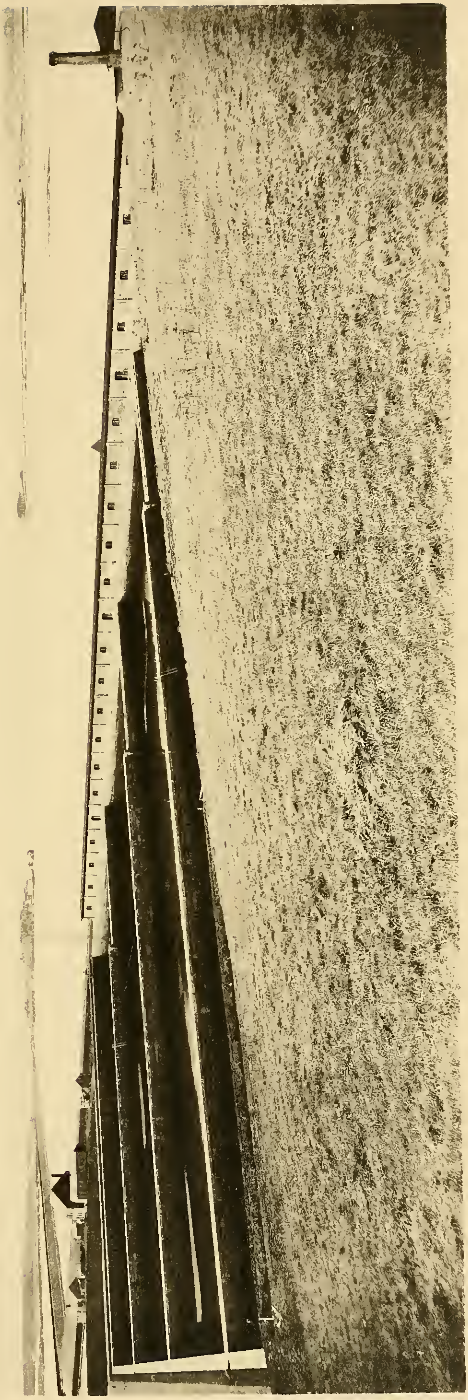
RESERVOIR AND OUTLET.

Moon Island is distant about a mile from the main land. It comprises about 36 acres of upland, surrounded by about 145 acres of beaches and flats. The easterly end of the island rises to an elevation about 100 feet above tide-water. On the western or landward side is another smaller area of rising ground, about 45 feet high. Between these two portions of high land was a valley, crossing the island from north to south, whose central portion was but a few feet above the level of high water. In this comparatively low land the reservoir is situated.

Plates XXIII. and XXIV. give views of the reservoir and its surroundings, reproduced from photographs. The former was taken from the high part of the island just east of the reservoir. It shows the embankment between Moon Island and Squantum, and also the flume, parallel to and south of the embankment. Near the centre of the plate the pumping-station can be dimly discerned, although partly hidden by a clump of trees on Thompson's Island. Plate XXIV. gives a nearer view of the reservoir, looking eastward. It shows one basin partly filled with sewage.

The reservoir, as at present built, covers an area of about five acres. It is expected that in the future, when the amount of sewage to be stored shall have increased, it will be necessary to extend and enlarge the reservoir to about double its present capacity. The portion already built is so located and arranged that the contemplated extension can readily be made on the south side of the present structure.

The site for the reservoir was prepared wholly by excavating. On the centre line of the valley this excavation was about ten feet deep, while on the east and west sides the cutting in places was forty feet deep. A drive-way surrounds the reservoir, and the banks are sloped back from it. The excavated material



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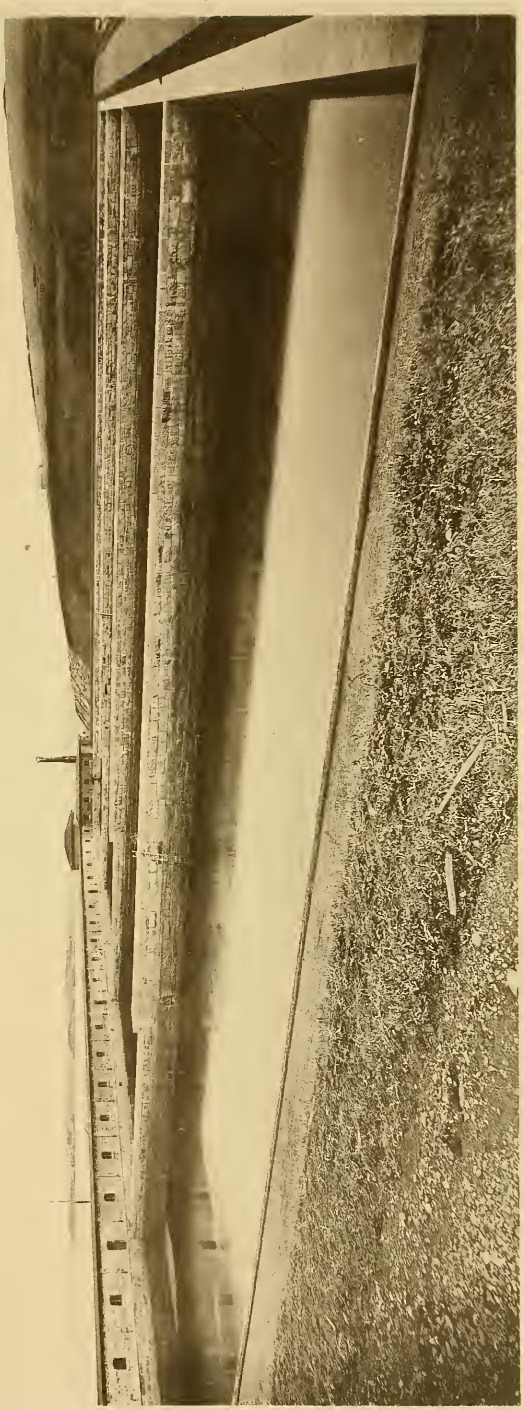
View of Reservoir and Outfall Sewer, looking towards City.

PLATE XXIV.



HELIOTYPE PRINTING CO., BOSTON

Storage Reservoir at Moon Island.

was chiefly hard clay; but a bed of gravel and sand was found near the centre of the valley, which, in places, went 20 feet below the reservoir bottom. Part of the reservoir, therefore, is founded on clay, and another smaller part on sand and gravel.

The earth was dug by steam-excavators, and was carried away in cars by locomotives. It was used for building the upper portion of the embankment between the island and main land. As more earth was needed for this purpose than could be supplied from the reservoir excavation a further quantity was borrowed from the island in such places and to such lines and grades as partly to prepare the site for the proposed future extension of the reservoir. In all, about 283,000 cubic yards of material were taken from the island, and the contractor's price for digging and disposing of it averaged about 59 cents per yard.

The retaining-walls of the reservoir (Fig. 2, Pl. XXVI.) are 17.5 feet high, and from 6 feet 10 inches to 7 feet 10 inches thick at the base. They are classed as rubble-stone masonry laid in mortar, and are built of split and quarry stone mostly brought from granite quarries in Maine. On top of the walls are large coping-stones with pointed surfaces. The rubble stones were laid in somewhat uneven courses. The reservoir is divided into four basins, of nearly equal area by three division walls (Fig. 3), built of the same class of masonry as that forming the retaining-walls. Rosendale cement mortar, made with one part of cement to two of sand, was used in building rubble-stone masonry. The contractor's price for this class of masonry was $7.47 per cubic yard.

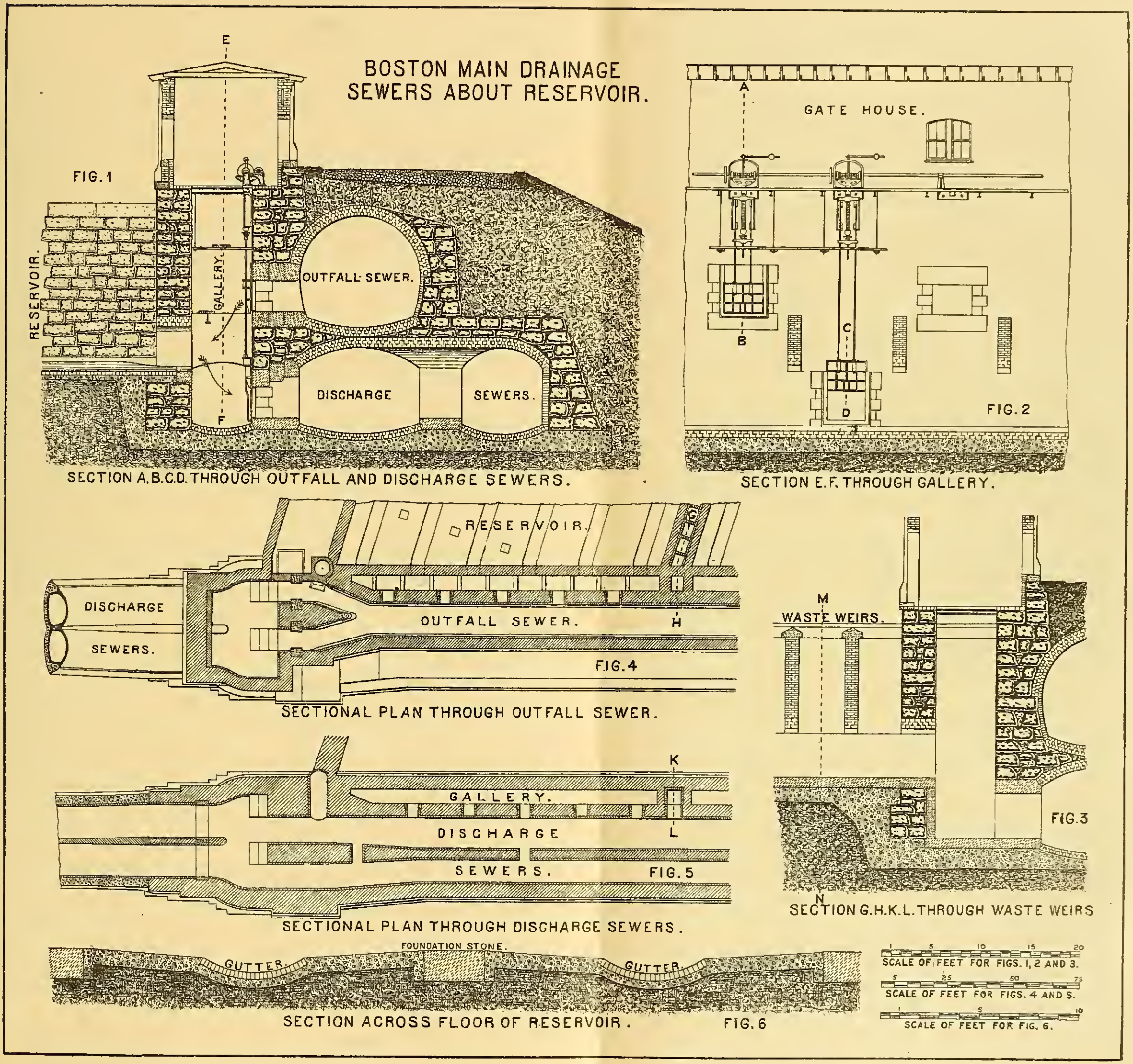
The floor of the reservoir consists of a bed of concrete, nine inches thick (Fig. 6, Plate XXV.). The lower five inches was made with Rosendale cement, sand, and pebbles, in the proportion of one, two, and five parts of each respectively. In the upper four inches of concrete Portland cement was substituted for Rosendale. The floor of each basin was shaped into alternate ridges and gutters. The gutters are paved with bricks set on edge.

Considering the distance of Moon Island from habitations, it did not seem that any just cause for complaint would be occasioned if the reservoir were left uncovered, and, therefore, no roof was built over it. But, to provide for any future contingency which might require it to be covered, foundation blocks were built into the floor, on which piers to support a roof can hereafter be built, if needed. These foundation blocks are spaced 20 feet apart in one direction, and 30 feet in the other, and consist of granite stones 3 feet square and 18 inches thick. They are rough pointed on top and are bedded in concrete. They cost, laid, $7.25 each.

The reservoir was divided into four distinct basins, in order that one or more of them might be kept empty for cleaning, or some similar purpose, while the others were in use. Under such conditions, however, there might be danger that water from a full basin would find its way down through the thin sheet of concrete under it, and, passing below the division wall, would blow up the floor of an adjacent empty basin. This would be especially apt to occur where the basins and walls are underlaid by the previous bed of gravel before referred to.

To diminish the liability to such a catastrophe, beneath all walls, not founded on clay, was driven a solid wall of tongued and grooved 4-inch sheet-piling. This protection penetrated the gravel stratum and entered the clay below it. As an additional precaution at such places a line of 10-inch drain-pipe was laid just below the floor on each side of the division wall. These drains were connected with others surrounding the reservoir outside of the retaining-walls. The drains within the reservoir also have 10-inch safety-valves opening into the basins. The drain-pipes were laid with open joints, and were surrounded, below the concrete, with dry-laid ballast and pebbles. Water accumulating beneath the floor of any basin has free access to the drain under that basin. Should any water find its way under a division wall it is immediately intercepted by the line of pipe just beyond the wall. Should a drain under an empty basin become gorged for any reason, the water is discharged into the basin, through the safety-valve, before sufficient head has accumulated to endanger the concrete.

The northerly 100 feet of each division wall, being the end nearest to the discharge sewers, is made hollow, and 1.75 feet


BOSTON MAIN DRAINAGE
SEWERS ABOUT RESERVOIR.
FIG. 1
E
RESERVOIR.
GALLERY.
OUTFALL SEWER.
DISCHARGE
SEWERS.
F
SECTION A.B.C.D. THROUGH OUTFALL AND DISCHARGE SEWERS.
GATE HOUSE.
A
B
C
D
FIG. 2
SECTION E.F. THROUGH GALLERY.
RESERVOIR.
DISCHARGE
SEWERS.
OUTFALL SEWER.
H
FIG. 4
SECTIONAL PLAN THROUGH OUTFALL SEWER.
M
WASTE WEIRS.
N
FIG. 3
SECTION G.H.K.L. THROUGH WASTE WEIRS
K
GALLERY.
DISCHARGE
L
SEWERS.
FIG. 5
SECTIONAL PLAN THROUGH DISCHARGE SEWERS.
FOUNDATION STONE.
GUTTER.
GUTTER.
SECTION ACROSS FLOOR OF RESERVOIR.
FIG. 6
1 5 10 15 20
SCALE OF FEET FOR FIGS. 1, 2 AND 3.
5 25 50 75
SCALE OF FEET FOR FIGS. 4 AND 5.
1 5 10
SCALE OF FEET FOR FIG. 6.

lower than the rest of the reservoir walls (Plate XXV., Fig. 4). Long chambers are thus formed, open on top, but otherwise enclosed within the walls. These chambers connect directly with the discharge sewers, and through them with the harbor. These portions of the division walls serve as waste wiers, by which the sewage in the basins can overflow, if, owing to negligence on the part of the employés, the gates which empty any basin should not be opened before the basin becomes too full.

The arrangements by which the sewage is turned from the outfall sewer into the reservoir and is again permitted to empty, through the discharge sewers, into the harbor, will be understood from an examination of Fig. 1, Plate XXV., which is a transverse section of said sewers. The upper sewer in the figure is a continuation of the outfall sewer, and extends along the whole front of the reservoir. Immediately below it are the discharge sewers, which also extend along the front of the reservoir, and, also, about 600 feet beyond it out into the sea.

In the side of the outfall sewer are 20 3 × 4 feet, cut-stone gate openings. Only eight of these are at present provided with gates, the others being bricked up until an increased amount of sewage and an extension of the reservoir shall require their use. In the side of the discharge sewer nearest the reservoir are also 20 gate openings, of which 12 are provided with gates. The two discharge sewers are connected directly by 11 large transverse passages. The amount of masonry contained in and surrounding the sewers equals that contained in all of the reservoir walls.

Between the sewers and the reservoirs is what is called the six-foot gallery. This serves as a protection for the gates against frost and as a foundation for a gate-house above. The hollow division-walls between the basins extend across the gallery and divide it into four sections, corresponding with the four basins of the reservoir. Brick brace-walls, about 10.5 feet apart, are thrown across from the sewers to the reservoir wall.

The 20 gates, with their frames and seats, are made of cast-iron. The frames were cast in one piece and closely fitted to the openings prepared in the masonry. They are secured to the stone by $\frac{7}{8}$-inch anchor-bolts, let in $4\frac{1}{2}$ inches and fastened with brimstone. The seat of each gate is a separate piece of cast-iron, planed $\frac{7}{8}$ inch thick, fastened to its frame with screw rivets, and scraped true and straight. Fastened to each side of the frame is a guide, which holds the valve in its proper position while moving. The face of the valve is planed and scraped to fit the facing of the frames, so that there shall be no leakage. The valve is pressed tight to its seat by means of adjustable gibs, which bear against inclined planes, cast on the guides.

The gates are made by lifting-rods and screws, connected with suitable brackets, gearing, and clutches, above the floor of the gate-house (Plate XXV., Fig. 2). A main line of shafting, from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches in diameter, extends the whole length of the gate-house, or about 575 feet. The clutches for each gate are thrown in and out by a hand lever, and also by the gate itself when it reaches either end of its course. The 20 gates, with all their appurtenances and the gearing and shafting for operating them, cost, in place, about $12,000.

To furnish power both a steam-engine and a turbine wheel are provided. The latter, which is most commonly used, is 21 inches in diameter, and is placed in a well near the north-easterly corner of the reservoir. It takes water either from the reservoir or from the outfall sewer, and drains into the discharge sewers. Under ordinary circumstances it furnishes without expense ample power for moving the gates, running pumps, and other necessary operations, and requires no attention beyond opening and shutting the gates leading to it.

The engine, which is seldom used, is of 30 horse-power. To furnish steam for it and also for heating in winter there are two upright tubular boilers. The machinery and gates are protected by suitable brick buildings, designed and built by the engineers. The principal one of these, called the Long Gate-House, extends for 575 feet along the front of the reservoir. Connecting with it, at the north-easterly corner of the reservoir, is another larger building, containing engine, boiler, and coal rooms. A chimney, 40 feet high, is also built.

CITY OF BOSTON MAIN DRAINAGE.

DISCHARGE SEWERS BEYOND RESERVOIR SHOWING PIER AND COFFER DAM.

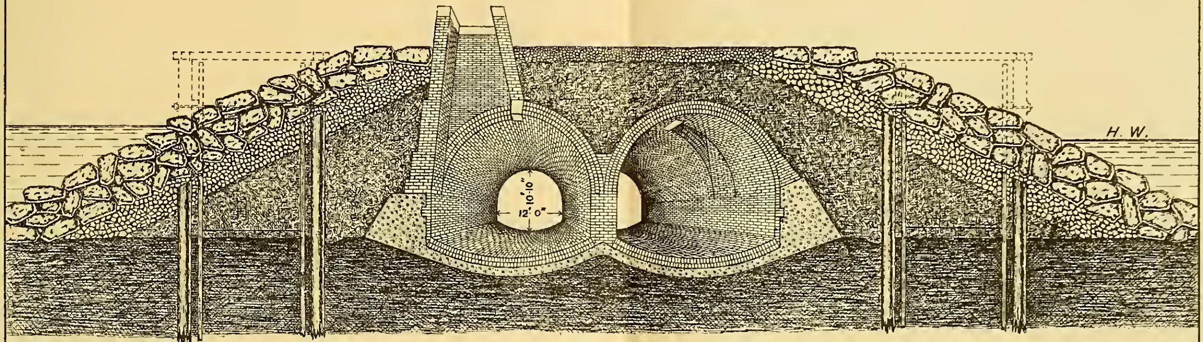


FIG. 1.

12" 0 1 2 3 4 5 6 7 8 9 10 11 12 FT.

SCALE OF FEET.

100 M. 0 1 2 3 M.

SCALE OF METRES.

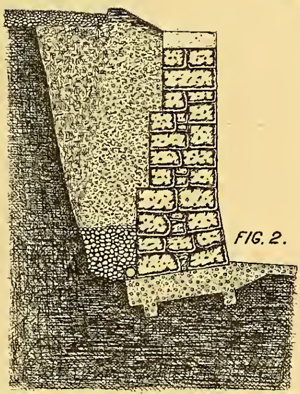


FIG. 2.

RETAINING WALL OF RESERVOIR GENERAL SECTION.

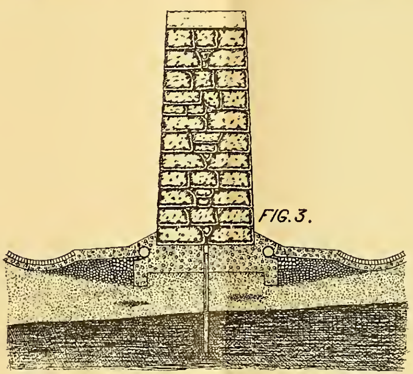


FIG. 3.

DIVISION WALL ON PERVIOUS MATERIAL.

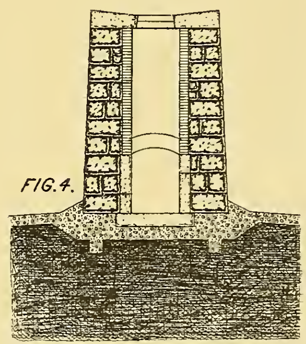


FIG. 4.

HOLLOW DIVISION WALL SECTION M. N. PL. XXV.

The sewage flows through the gates in the outfall sewer into the six-feet gallery, whence it passes through openings in the reservoir wall into the reservoir. There it accumulates during the latter part of ebb-tide and the whole of the flood-tide. Shortly after the turn of the tide the lower gates are opened, and the sewage flows from the reservoir, through the gallery, into the discharge sewers, which conduct it to the outlet.

That portion of the discharge sewers beyond the reservoir was called the Outlet-Sewer Section, and was built under a separate contract. There are two sewers of brick and concrete masonry (Fig. 1, Plate XXVI.), each 10 feet 10 inches high, by 12 feet wide inside. They extend from the reservoir about 600 feet out into the sea, where there is five feet depth of water at low tide. The bottoms of the sewers are 1.5 feet above the elevation of low water. The arches, 12 inches thick, were laid with Rosendale cement mortar, and the inverts and sides with Portland cement mortar. In the top of each sewer are built three large vent holes, to relieve the arch from any pressure of air due to a succession of waves entering the sewers.

The immediate outlet consists of a cut granite pier-head laid in mortar. In this are chambers containing grooves for gates and stop-planks. The stones forming the pier-head are quite large, in order to withstand waves and ice. Several of them weighed about eight tons each. Most of the horizontal joints are dowelled, and the vertical joints of the coping-stones are secured by gun-metal cramps.

The sewers are covered by an earth embankment, with its side slopes protected by ballast and riprap. This embankment constitutes a pier extending into the harbor, and its top is ballasted and surfaced for a roadway. Near the end of the pier is a strong wharf, about 40 feet square, supported by oak piles. This is used for landing coal and other supplies.

To facilitate construction on this section the site of the work was enclosed by building about 1,100 feet of coffer-dam around it. The dam consisted of two rows of spruce piles, ten feet apart, the piles in each row being spaced six feet on centres. Inside the piles were rows of 4-inch tongued and grooved sheet piling.

The dam was tied across with iron bolts and was filled with earth. When pumped out it proved to be very tight, and enabled the work inside it to proceed without interruption. After the sewers were built and covered, the dam was cut down below the surface of the embankment slopes. The total cost of this outlet section was $96,250.

The top of the reservoir floor is about one foot below the elevation of high water. The paved gutters are a little lower, and incline nearly a foot from the back of the reservoir to its front. This insures there being a good current in them when the reservoirs are nearly emptied, so that the light deposit of sludge which has been precipitated upon the bottom of the reservoir is mostly washed into the discharge sewers.

To assist in cleansing the basins a system of pipes and hydrants furnishing salt water under pressure is provided. The water is drawn from the sea to a pump in the engine-house, which forces it about the reservoir. A 4-inch pipe, with double hydrants, about 75 feet apart, is laid through the middle of each basin. A line of hose can be connected with any hydrant, and a fire-stream directed against any part of the floor or side walls. The pump can also be used to pump sewage with which to irrigate the banks and grounds surrounding the reservoir.

To obtain fresh water for domestic purposes, and for the boilers, the high portion of the island has been encircled with ditches which collect rain-water and conduct it to a cistern holding 75,000 gallons.

Within the gate-house is provided an automatic recording gauge, moved by clock-work, and connected with floats in the sewers. The records traced by this machine furnish a perfect check on the vigilance of the employés. Each day's record shows, by inspection, the hours at which the gates were opened and closed, and the height of tide.

The total expenditure by the city on account of Main Drainage Works, from the beginning of the preliminary survey, 1876, to the present time, is about $5,213,000.

CHAPTER X.

DETAILS OF ENGINEERING AND CONSTRUCTION.

About one-half of the work required to complete the Main Drainage System was done by contract, and the rest by day's labor, under superintendents appointed by the city. The general rule by which it was decided whether any given section of work should be built by contract, or not, was this: if the work was of such a nature that its extent and character could be determined in advance, so that full and explicit specifications for it could be drawn, it was let out by contract to the lowest responsible bidder. If, on the other hand, all of the conditions liable to affect the work could not be ascertained, so that it was anticipated that modifications in the proposed methods of construction might prove necessary or desirable, the work was done by day's labor.

Thus, wherever in suburban or thinly populated districts the character of the earth to be excavated was supposed to be of uniform quality, most of the sewers there located were built by contract. Those located in crowded thoroughfares, where it was necessary to interfere as little as possible with the use of the street, and those in places where there was liability of encountering deep beds of mud, old walls, wharves, and other obstacles, were built by day's labor.

There was little difference in the quality of the work obtained by these different methods of construction. The contract work was built under more favorable conditions, and as a whole is somewhat superior to the other. It also, as a rule, cost much less. Several reasons can be given for this fact. The physical conditions were generally more favorable. Low prices were obtained through competitive bids. Most of the contractors made no profit; some even lost money. The contract work was largely done during the first few years of construction, when all prices were lower; while the bulk of the work done by day's labor was built later, when prices for labor and materials had risen. The wages paid city laborers were fixed by the City Council, and were always higher than the market rates. At times the city superintendents were not untrammelled in respect to hiring and discharging their employés.

Sixteen sections of sewer were let by contract. In two cases the contractors failed, and the sections were relet. In four other cases the contractors abandoned their work, which was completed by the city, by day's labor. In connection with the Main Drainage system about 50 more contracts were made for materials and machinery, and for construction and work other than sewer building. These contracts were drawn by the engineers.

In preparing a contract for building a sewer the object kept in view was to describe only the general character of the work, and to leave for further decisions, as construction progressed, the exact shape, methods of construction, and amounts and kinds of materials to be used. That this might be done without unfairness to the contractor the precise character (but not the amount) of every kind of work and material, which might be called for, was specified, and a price was agreed on for each. Should anything not specified be called for, the contractor agreed to furnish it at its actual cost to him, plus 15 per cent. of said cost.

This is a convenient form of contract, because it permits the engineer to modify his methods of construction whenever experience shows that a change is desirable. One kind of material can be substituted for another; cradles, side-walls, and piling can be added or discarded. Rather more opportunities for contention are afforded by this form of contract than by a simpler one; but, on the whole, it was considered the best for our purposes.

Contract work was carefully watched, an inspector being continually on the ground. Great care was taken to select suitable men for such positions. They were all experienced masons, and were paid $4.00 or more a day.

A daily force account was always kept, both of work done by the city and that built by contract. This recorded the number of hours' labor of every class and the amount of material which entered into each part of the work, so that its cost could be ascertained. On contract work this record proved very useful, because it furnished conclusive evidence in any case of disagreement as to quantities or cost.

All materials were carefully inspected for quality. Especial care was exercised in inspecting bricks and cement. About 50,000,000 of the former and 180,000 casks of the latter material were used in building the works. It was required that the bricks should be uniform in size, regular in shape, tough, and burned very hard entirely through. Bricks with black ends were not excluded if otherwise suitable. No machine-made bricks were accepted, as they were usually found to have a laminated structure. A moderate proportion of bats was allowed, but only in the outer ring of the covering arch. From the accepted bricks the most regular were culled out for inside work. Bricks from different localities varied considerably in size, and this fact, so often disregarded, was taken into account in making purchases for the city. For instance, 1,175 Bangor bricks were required to build as much masonry as could be built with 1,000 Somerville bricks.

A requirement that no bricks should be used which would absorb more than 16 per cent., in volume, of water, although not always enforced, was occasionally found useful, because it permitted the rejection of bricks made of light, sandy stock, which were, however, perfectly hard and shapely. The following was the method employed in testing for porosity: The brick to be tested was first dried thoroughly by artificial heat, and then weighed. Next it was put in a pan containing one-half inch of water and allowed to soak for 24 hours, the pan being gradually filled, by adding water from time to time until the brick was covered. When thoroughly soaked it was again weighed, both in water and in air. The difference between the weights dry and soaked, in air, was the weight of water absorbed, and the difference between the weights of the soaked brick, in air and in water, was the loss of weight in water, *i.e.*, the weight of a bulk of water equal to that of the brick; then $\frac{\text{The weight of water absorbed}}{\text{The loss of weight in water}}$ was the proportion, in volume, of water absorbed by the brick.

Natural "Rosendale" cement was chiefly used on the work, but about 26,000 barrels of Portland cement and a little Roman cement were also used. Portland cement mortar was often used in building the inverts of sewers and, in general, where there was liability to abrasion or where especial strength was needed. It was often mixed with Rosendale cement, in order to make a somewhat stronger mortar. Very quick-setting Roman cement was used for stopping leaks, and was also mixed with other cements for wet work, because it would set at once and keep the mortar from being washed down before the stronger cements had hardened.

In Appendix A are given a full account of the methods employed for testing cement, and also the results derived from the tests made for experimental purposes. One advantage resulting from the careful and systematic testing was that manufacturers and dealers were themselves careful to offer or send no cement but that which they felt confident would be accepted. During the first year or two much of the cement offered was rejected, but later very little of it proved unacceptable. In making contracts for cement a standard of strength and fineness was seldom given. It was simply stipulated that the cement should be, in every respect, satisfactory to the engineer, and, if not satisfactory, should be rejected.

In one contract, however, for 5,000 barrels of Portland cement, a certain fineness and strength were required. As some of the specifications of this contract are believed to be novel and practically useful, they are here cited: —

Fineness. The cement to be very fine ground, so that not over fifteen (15) per cent. of it will be retained by a certain sieve deposited in the office of the City Engineer of Boston, said sieve having 14,400 meshes to the square inch.

Strength. The cement when gauged with three parts by measure of sand, to one part of cement; formed into briquettes having a breaking area of 2¼ square inches; kept 28 days in water and broken from the water, to have a tensile strength of 150 lbs. per square inch.

Price. We agree to receive as full payment for the satisfactory delivery of said cement, subject to its fulfilment of the foregoing requirements, as determined by the City Engineer of Boston, the sum of three dollars ($3.00) per cask delivered and accepted.

We further agree, that, shall the cement, or any portion thereof, fail to fulfil the above-mentioned requirement as to fineness, but shall nevertheless be accepted by the city, we will receive as full payment for said cement, or said portion thereof, a sum to be determined by the City Engineer, by deducting from the full price, of three dollars ($3.00) per cask, the sum of two cents ($0.2) per cask for each per cent. greater than 15 per cent. that is retained by the sieve before mentioned.

Contractors were required to use only clean, sharp, coarse sand for making mortar. On city work, if clean sand was not conveniently accessible, a moderately dusty or dirty sand was considered almost as good, and quite good enough. So, also, in making concrete, contractors were obliged to use screened sand and stone; but a city superintendent might mix his cement directly with the gravel dug from the bank, if it was more convenient and cheaper to do so. Comparative tests of concrete made by these different methods failed to distinguish any superiority in one over the other.

The city sewers were so low that the intercepting sewers, which had to be lower still, required unusually deep trenches. The average depth of cut for the whole system was more than 21 feet. The bottom of these trenches was generally several feet below the elevation of low tide. As the new sewers followed the margins of the city near the sea, tide-water frequently found access to the trenches, so that construction could only proceed during a few hours at about the time of low tide, when the leakage of water could be controlled. Sometimes the trench could not be kept entirely free from water. Many of the streets traversed by the sewers were underlaid by beds of mud. Generally the mud was not so deep but that an unyielding foundation could be secured by driving piles through the mud down into the hard ground beneath. Sometimes, however, the mud was so deep that hard bottom could not be reached by piling.

It was under such conditions that the use of wood to form the whole, or the lower part, of the sewer was resorted to. Wood was no cheaper in itself than masonry; but a wooden sewer could be built very much more rapidly than a brick one, and could be built by unskilled laborers. Also, a wooden invert could be fastened in place, if necessary, under a foot or two of water. Moreover, a wooden sewer, fastened by spikes and oak treenails, possessed considerable elasticity, and could settle slightly in places, or assume an undulating form, without breaking.

Therefore, under conditions such as those just mentioned, the use of wood to form the shell of a sewer was often resorted to. There were disadvantages attending this mode of construction. The elasticity which permitted the sewer to bend longitudinally without breaking, also made it tend to yield transversely, sinking at the crown and bulging at the sides, whenever the earth outside was at all compressible. It was not easy to prevent the wooden shell from leaking badly, especially at the end joints. All wooden sewers had to be lined with brickwork, or concrete, to make them smooth and tight; but putting such lining inside of a leaky sewer is a somewhat tedious and difficult operation.

The tops of most of the intercepting sewers are several feet below the level at which ground water stands in the earth about them. Great pains were taken to insure every joint being thoroughly filled with mortar, and the arches were always plastered outside with a half-inch coating of cement mortar. By such means the greater part of the system was made perfectly tight and dry. In places, however, especially where there were slight settlements and cracks, a considerable amount of leakage occurred. All leaky joints were calked as well as possible. Various materials were used for this purpose. Among them were neat cement; cement mixed with grease or with clay; oakum; dry pine wedges, and sheet lead. By one or several of hese methods the leakage could either be entirely stopped or reduced to an insignificant amount.

A considerable item in the total cost of building the intercepting system was the expense incurred in repairs to street surfaces and paving, over the sewers. The trenches were so large and deep that the backfilling, often of a peaty consistency, could not be sufficiently compacted by ramming or puddling, but continued to settle for a year or more after the sewer was built. As it was necessary to keep the surface in a safe and reasonably smooth condition the portion over the trench was sometimes repaved three, or even more, times before it would remain permanently in place. Where the earth underlying the street was of a peaty nature it would be rendered spongy and compressible by its water draining out into the open trench during construction. Then the whole street surface, including sidewalks and sometimes even adjacent yards, would settle out of shape and need repairing.

Another source of expense and trouble was the breaking of house-drains where they passed across the sewer trench, due to the settlement of the backfilling. The intercepting sewers were frequently, indeed generally, built in streets which already contained a common sewer. The house-drains from one side of the street crossed the trench of the intercepting sewer. These drains were maintained, or replaced, as securely as possible, but many of them were afterwards broken. These were generally found to be sheared off on the line of the sides of the excavation, and the portion within the trench sunk bodily, half a foot or so, below the rest.

As a rule the streets in which sewers were built were kept open for traffic. When the trench was in the middle of the street, passage-ways for vehicles were maintained on both sides of it, even when the width between sidewalk curbs was only 26 feet. This was accomplished by the use of an apparatus for excavating and backfilling, invented by the superintendent, Mr. H. A. Carson, and afterwards patented by him. Various merits are claimed for it, but the chief advantage in its use at Boston was, that by it sewers could be built with very little encroachment on the surface of the street. Views of the apparatus are given on Plate XXVII. Although a patented article, a brief description of it seems proper, since it was used in building more than one-half of the intercepting sewers.

In its general features the apparatus consisted of a light frame structure, extending longitudinally over the sewer trench from a point in advance of where excavation had begun to another behind where the trench was completely backfilled. All operations, therefore, were carried on beneath the machine. Excavation proceeded under the forward portion of the frame, the sewer was built under the central portion, and backfilling progressed near the rear. A double-drum hoisting-engine was carried on a platform at the front end of the frame. From the top of the frame were suspended iron tracks, on which were travellers, moved backwards and forwards by wire ropes leading to the engine. A number of tubs, loaded by the diggers in front, were hoisted simultaneously by the engine, and run back to be dumped over the completed sewer. They were then returned and lowered to the points whence they had been taken, by which time a second set of tubs had been filled ready for hoisting.

Any surplus earth was dumped through a hopper into carts which were backed under the machine. When it was necessary to furnish a passage across the work the trench was bridged, and the frame trussed. When one section of excavation was completed the whole apparatus, which rested on wheels, was pulled forward 30 or more feet by its own engine. The average total length of one apparatus was 200 feet, and its total weight about 10 tons.

Sewer-building, done by the city, was frequently carried on through the winter months. Contractors, on the other hand, were not allowed to lay masonry between November 15 and April 15. The temperature at the bottom of a deep trench was always considerably higher than that at the surface of the ground; so that it was only when the mercury was at ten or more degrees (F.) below the freezing-point that work was suspended. Much extra precautionary work was needed. Bricks were steamed in a close box before using; sand and water were warmed, and completed work was protected by coverings of straw or sea-weed. Winter work was not economical, and was resorted to chiefly for the purpose of employing laborers, who otherwise might have been idle.

Experience is probably a better guide to designing stable sewers than are theories concerning lines of pressures and geostatic arches. The physical conditions which determine the direction and amount of the earth pressures are seldom the same in the case of any two sewers. They differ at different points about the same sewer, and often are not alike on both sides of one sewer. The best that can be done is to judge as well as possible of the character of the ground to be penetrated, and

TRENCH MACHINE

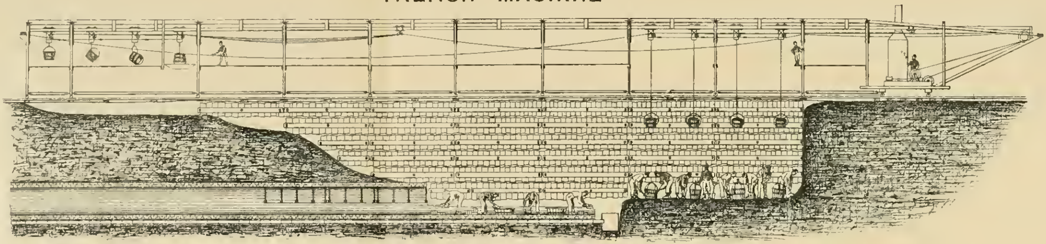


Fig. 1

MT. VERNON ST. 1883.

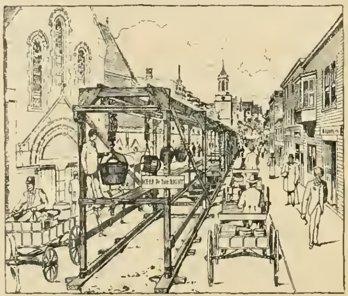
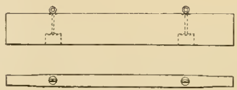


Fig. 2

CITY OF BOSTON

MAIN DRAINAGE



STOP PLANKS

Fig. 3

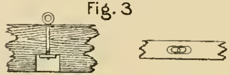


DIAGRAM MACHINE

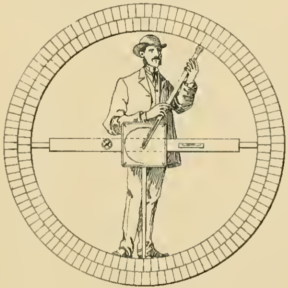


Fig. 4

begin to build such a sewer as has proved stable under similar conditions. The sewer should then be examined carefully, during and after loading, for signs of weakness.

In the case of the main drainage sewers such examinations were made graphically, by taking diagrams of their inside shape. These diagrams were taken by the aid of a machine shown on Plate XXVII. It consisted of a light frame, which could be so fixed against the masonry that its centre should be in the axis of the sewer. A movable arm was then rotated radially from the centre, with its outer end bearing lightly against the inside perimeter of the sewer. At the centre of the machine was a disk, on which was placed a sheet of paper. A pencil point, attached to the rotating arm, traced upon the paper a diagram, showing the shape of the sewer and its variation, if any, from the established form.

The shape and amount of any distortion suggested the cause which produced it, and the remedy to be applied. The most common causes were too early removal of centres; too rapid or unequal loading; the use of improper material for backfilling about the sewer; insufficient ramming of backfilling against the haunches; with drawing sheetplanks after backfilling; inherent weakness in the design of the sewer. Such errors could be corrected and the design of the structure could be modified until the diagrams taken from the sewer were found to correspond with its proper shape.

The Main Drainage System is so arranged that any principal portion of it can be isolated and emptied for inspection and repair. Any intercepting sewer can be thus isolated by closing the penstock gate at its lower end, and also the inlet-valves connecting it with the common sewers, the latter then discharging at their old outlets. By closing the gates at the ends of all intercepting sewers the main sewer can be emptied. Wherever an opportunity for isolating a small portion of the works might prove desirable, but the use of iron gates for such purpose would have entailed unwarranted expense, as a cheaper substitute, grooves of iron or stone were built into the masonry for stop-planks. Such grooves for stop-planks were always built above any iron gates, to afford a means of access in case of needed repairs. Where slight leakage could be afforded, a single pair of grooves was considered sufficient. Where a tight dam was desirable, a double set of grooves was provided, so that a double set of stop-planks, with an inside packing of clay, could be used. Some hundreds of stop-planks, of different lengths, are kept in readiness. Their form is shown on Plate XXVII. They are made of hard-pine planks, from three to five inches thick, planed and oiled.

The connections between the common sewers and the intercepting sewers were usually made during the construction of the latter. The valves of the inlet-pipes, built into the common sewers, were closed and made tight by a little cement around their edges. By raising these valves the connection between the old and new system could at any time be established.

CHAPTER XI.

WORKING OF THE NEW SYSTEM.

January 1, 1884, the connections between the common and intercepting sewers were first opened. Pumping began at the same time, and the sewage was sent to the reservoir at Moon Island, and thence discharged into the Outer Harbor. Connection with about one-half of the common sewers was made on that day, and most of the others were connected within a month thereafter; so that by February, 1884, nearly all of the city sewage was diverted from the old outlets. The upper portion of the West Side intercepting sewer, in Lowell and Causeway Streets, was built in 1884. The common sewers, tributary to it, were intercepted as construction progressed. A common sewer draining a portion of Dorchester, intercepted by the main sewer at East Chester Park just east of the N.Y. & N.E. Railroad, was not connected until early in 1885.

Although the whole intercepting system, therefore, was not entirely completed until the present year, yet the greater part of it has been in operation for fifteen months, — a long enough period to afford a fair indication of its practical working, and of the results which will be derived from it.

As elsewhere stated the Main Drainage Works were designed and built to correct two principal evils inherent in the old system of sewerage. These were: —

First. The damming up of the common sewers by the tide, by which, for much of the time, they were converted into stagnant cesspools, and the air in them was compressed, and to find outlets was driven into house-drains and other openings.

Second. The discharge of the sewage on the shores of the city in the immediate vicinity of population, thereby causing nuisances at many points.

The first of these evils has been entirely corrected by the new system. The old sewers now have a continual flow in them, independent of the stage of the tide, as has been ascertained by frequent observations, and also from the testimony of drain-layers, who formerly were only able to enter house-pipes into the sewers when the latter were empty at low tide, but now can make such connections at any time.

The new system has also substantially remedied the second evil. From the moment that any of the city sewers was connected with an intercepting sewer, the sewage which had before discharged on the shore of the city was diverted, and has since been conveyed to Moon Island and emptied into the Outer Harbor at that point.

It is true that about twenty-four times during the past year, or an average of twice a month, during rain-storms and freshets, the amount of water flowing in the sewers has exceeded the capacity of the pumps. At such times the excess has been discharged at the old sewer outlets. But this occasional and temporary discharge of very dilute sewage does not seem to have occasioned any nuisance. Examinations and inquiries concerning the condition of the shores and docks at the sewer outlets have shown that water, once continually foul, has become pure, bad odors have ceased, and fish have returned to places where none had been seen for years. The stenches, referred to by the City Board of Health (p. 13), which formerly, at times, were prevalent over the city, were not noticed during the past year.

The attempt to relieve certain low districts, subject to flooding of cellars during rain-storms at high tide, by discriminating in favor of such districts in respect to the interception of storm-water, has met with marked success. No case of flooding in such districts has been reported since the sewers draining them have been connected with the intercepters; and many cellars, which used often to be filled several feet deep with water, are known to have been perfectly dry during the past year.

Building the intercepting sewers has also dried cellars in other parts of the city in a way which was not at first anticipated. When land on the shores of the city was reclaimed for building purposes, most of the old walls and wharves were covered up by the new filling. Tide-water followed along any such structures through the ground, and entered cellars lower than high-tide level. The new sewers were generally built along the present margins of the city, and in digging deep trenches for them the old structures found were cut off and removed. The backfilled earth in the trenches forms an impervious dam surrounding the city, beyond which tide-water cannot pass.

The sewers have been examined frequently since they went into operation. The average depth of dry-weather flow in the intercepting sewers is from ten to twenty inches, so that they can be entered on foot. So, also, can the main sewer above Tremont Street, and, sometimes, above Albany Street. Below that point the dry-weather flow is from two to three feet deep, necessitating the use of a boat.

The velocity of flow in the sewers varies from about two feet a second upwards. An attempt was made to measure the velocity at several points with a current meter. While integrating, the meter could be rarely kept under water longer than ten seconds at a time without danger of its being clogged by paper, hair, and similar substances. By the use of a stop-watch the instrument could be removed for cleaning and again immersed without interfering with the experiment. The inclination of the surface of the sewage, though approximately the same as that of the sewer, was seldom precisely the same, and the observations were not sufficiently exact, in any case, to determine just what inclination then existed. The mean velocity at the points of measurement were, however, accurately ascertained, and the results may be of sufficient interest to cite.

In the case of a 4 × 4.5 feet sewer (Fig. 7, Plate VIII.), with an inclination of 1 in 2,000, flowing 1.23 feet deep, the mean velocity was 1.9 feet per second. This sewer had some gravel on its bottom. In the case of a 4.75 × 5.5 feet sewer (Fig. 8, Plate VIII.), with an inclination of 1 in 2,000, the depth was 1.45 feet, and the mean velocity was 2.45 feet per second. In a 4.5 feet circular sewer, with an inclination of 1 in 700, and a depth of 1.15 feet, the mean velocity of flow was 2.56 feet per second. In the case of an 8.25 feet circular sewer (Fig. 14, Plate VI.), the inclination being 1 in 2,500 and the depth 1.76 feet, the mean velocity was 2.59 feet per second, sufficient to keep in suspension and carry along all sewage sludge. Most of the city sewers, when first intercepted, were found to contain deposits of sludge varying from a few inches to several feet in depth. All these deposits were carried into the intercepting sewers, and the sludge reached the pumping-station and was pumped up into the deposit sewers. Gravel, stones, and brick-bats also were swept along and taken out at the filth-hoist. Fine sand, however, did not move so freely, but settled in ridges here and there, and had to be removed by hand.

The bottoms of the sewers are, as a rule, perfectly clean. No slime accumulates there, or, if it ever begins to grow, it is at once scoured off by the attrition of moving particles. The sides of the invert below the surface of the water have a thin coating of slime, making them very slippery. The arch and the portion of the invert above the water exposed to the air are clean, and often quite dry. In some portions of the sewers earthy accretions form on the arch. Where the sewer is surrounded by marsh mud these are turned black by sulphuretted hydrogen, sometimes they are colored yellow by iron, often they appear as white stalactites. In clayey soil the arch seems to be about as clean as when laid.

The atmosphere in the sewers is not offensive, although a faint sewage smell can be detected on first entering them. For the first eight months after the sewers went into operation they were not ventilated at the man-holes. This was because it was known that much sludge would be turned into them from the common sewers, and it was feared the smell from it might be noticed. Finally the ventilating covers, shown on Plate VI., were put in place. No smell has ever been noticed from them, and they considerably improved the condition of the atmosphere in the sewers, which is now quite fresh and hardly at all disagreeable; not so much so, for instance, as is that in most railway carriages after an hour's use. The temperature of the sewage varies from 50° to 65° F., and that of the air in the sewers from 40° to 60° F., depending upon the outside temperature.

A small force of men has been constantly employed, during the past year, in caring for the main and intercepting sewers. This force has consisted of a foreman, one carpenter, and four laborers. They have also done minor items of work and repairs which might properly be charged to construction. After every rain, whenever there was any likehood that water might have overflowed at the old outlets, all of the tide-gates have been visited. As a rule they are found to be quite tight. Occasionally one pair of a set (but never both pairs) are found to be leaking somewhat at high tide. This is caused by rags, corks, pieces of wood, or other such matters, catching near the hinges. At such visits the gates are washed clean, the hinges greased, and the iron-work examined for traces of incipient rust.

Some of the tide-gates were made of white-pine and some of spruce. A few of the latter, which have been in place for three years, already show signs of decay. These are inside gates situated above the elevation of mean tide, so that they are comparatively seldom wet. To replace them creosoted lumber will probably be used. The rubber gaskets, fastened to the gates, are in perfectly good condition after about three years' use. They were made of what was called by the manufacturer "pure rubber;" but, as they cost 75 cents a pound, when crude rubber was selling at more than a $1.00 a pound, they probably merely contained a larger percentage of that material than is usual in rubber goods. They were made with special reference to resisting the effects of sewage and grease.

The penstocks, flushing gates, and regulators are also inspected periodically. Moving parts are cleaned, slushed, and moved, so as to insure their being in good working condition. The iron, when carefully painted, does not appear to suffer from rust. About once in eight months it receives a coat of asphaltum paint. Duplicates are provided of all pins and other small parts, so that these can be taken to the yard to be warmed and recoated. The chains attached to the inlet-valves, by which they are lifted, are most subject to rust. These are frequently changed and taken to the yard, where, after being cleaned and scraped, they are warmed in a furnace and coated with hot pitch.

The catch-pails under the ventilating man-hole covers are emptied as occasion demands. In some localities, and at some seasons, pails will be filled in less than a month. Others will not require attention for three months. Men drive along the sewer line with a cart, remove a man-hole cover, lift out the pail, empty its contents into the cart, and again replace the pail and cover. A few extra pails are carried in the cart, so that if any one of those in use shows signs of rust it can be replaced by another, and be taken to the yard for cleaning and recoating.

The filth-hoist at the pumping-station seems satisfactorily to answer the purpose for which it was designed. In dry weather the cages are raised three times a day, and the average daily yield from them is about 16 cubic feet. The matters intercepted are rags, paper, corks, half lemons, lumps of fat, dead animals, pieces of wood, bottles, children's toys, pocket-books, and such-like miscellaneous articles, which by accident or design are thrown into house-pipes. Comparatively little solid fecal matter is caught, as most of it dissolves before reaching this point.

When it rains, and deposits are scoured out of the old sewers, very much more filth is caught in the cages. The amount sometimes equals three or four cubic yards in 24 hours. At such times it is necessary to raise and clean the cages every half-hour during the night as well as in the day, in order to prevent their becoming clogged and backing up the sewage in front of them.

At first what was removed from the cages was buried in pits near the pumping-station. This not being considered a satisfactory method of disposal, an attempt was made to burn the filth in the furnaces under the boilers. It was found that the filth, as taken from the cages, contained so much water that the fires were injured. Accordingly a simple press, like a cider-press, was procured, by which most of the water was pressed out. The comparatively dry cakes remaining after pressing are now burned without injuriously affecting the furnace fires.

The two high-duty "Leavitt" pumping-engines and the two storm-duty "Worthington" pumping-engines have all been run more or less during the past year. Any one of them is able to pump the ordinary dry-weather flow of sewage. As a rule one of the Leavitt engines is kept running; should it rain, and additional pumping capacity be needed, the second Leavitt engine is, by preference, started; if still more capacity is needed, the Worthington engines are started. When the amount of water arriving by the sewer decreases, the Worthington engines are first stopped.

The average daily quantity of sewage pumped in dry weather is about 24,000,000 gallons, and the average number of tons of coal consumed in doing the work is about $3\frac{1}{4}$. This, with some steam used for other purposes, gives a working duty in the case of the Leavitt engine of about 95,000,000 pounds raised 1 foot high by the consumption of 100 pounds of coal. The Worthington engines, under similar conditions, show a working duty of somewhat more than 50,000,000 foot-pounds.

The following table gives the results of the first year's pumping, beginning with February, 1884, when the works had got fairly into operation: —

Month. 1884.	Daily Average Gallons Pumped.	Daily Average Pounds of Coal.	Per Cent. of Ashes.	Gallons Pumped per Pound of Coal.	Rainfall.	
					Inches.	Number of Days it Rained.
February . .	25,777,360	14,028	15.8	1,836	5.74	20
March . . .	32,437,379	18,880	14.8	1,709	4.86	19
April	29,949,356	15,671	16.2	1,913	4.76	17
May	25,121,056	13,127	15.6	1,915	3.31	11
June	26,712,298	13,265	16.5	2,015	4.01	7
July	25,900,400	13,529	19.2	1,912	4.25	17
August . . .	31,674,621	14,704	16.0	2,174	5.01	14
September . .	28,412,431	11,099	12.1	2,568	.31	8
October . . .	27,601,557	10,206	13.3	2,698	3.17	13
November . .	27,501,283	8,985	8.0	3,073	3.03	9
December . .	30,883,501	10,181	7.2	2,885	4.46	15
1885.						
January . . .	38,498,668	11,448	7.2	3,265	5.33	9

It will be seen that the daily average, as given, is larger than the dry-weather flow, because it includes the extra quantities pumped during rains. The largest day's work thus far has been 81,280,883 gallons, but for a few hours this rate has been much exceeded. Until August, 1884, the pumping was not done economically. At that time a change was made in the management of the station, with a considerable increase in economy. A further gain was made in November, 1884, by substituting bituminous coal for anthracite, which had previously been used. The former coal makes more steam, and costs about $1 less a ton. The comparatively low duty shown by the table for December is due to the fact that the Worthington engines were largely used during that month, while a temporary building over the Leavitt engines was being taken down.

There are no means for determining accurately the actual amount of the city water-supply in the district whose sewers are tributary to the Main Drainage System. But it is evident that even in dry weather the amount of sewage reaching the pumping-station by the main sewer is greater than the water-supply of the districts drained by it. The excess is not constant; sometimes it is estimated to be 10 per cent. of the whole, and at other times it is probably 25 per cent., or even more. This excess comes from several sources. Many dwellings and factories in sewered districts have private water supplies. Breweries, and other similar large establishments, contribute largely in this way. A single sugar-refinery was found to pump and use, daily, about 1,000,000 gallons of salt water, all of which properly might have gone back into the harbor, but was, instead, turned into the sewers. In the spring, when the ground is full of water, much of it leaks into the common sewers, and is by them carried to the intercepters. Sea-water also, at high tide, finds its way along some of the old box-sewers, and leaks into them back of the tide-gates. It will probably prove to be true economy to rebuild many of the old sewers, in whole or in part.

The permanent working force employed at the pumping-station at present is as follows: —

1 Chief Engineer,
3 Assistant Engineers,
9 Oilers,
3 Firemen,
3 Coal-passers,
1 Clerk.

The men employed in the filth-hoist, included in the above, rank as oilers. The administration at this point is, of course, not as economical as it would be if there were a uniform constant amount of work to be done.

The deposit-sewers have perfectly answered their purposes in arresting all heavy matters contained in the sewage. The cross-sectional area of these sewers is so large and the resulting velocity of flow is so sluggish, even when four pumps are running, that all suspended matters subside before reaching the tunnel. Sand and gravel are deposited at once, as soon as they enter the sewers; lighter substances are carried a little farther; but only floating matters or those having about the same specific gravity as water, remain in suspension long enough to reach the farther end of the sewers.

As elsewhere stated, the sludge, contained by the common sewers at the time connection was made between them and the intercepting sewer, passed to the pumping-station and was pumped into the deposit sewers. The amount of this was 12,000 cubic yards or more. The best way of removing it was long considered, and it was only in the autumn of 1884 that the appliances described in Chapter VIII. were adopted and constructed. When the six-inch pipe connecting one deposit sewer with the sludge-tank was first opened, the deposits near where the pipe entered the sewer were drawn into the tank, which in the space of two days was filled with about 100 yards of sludge.

The floating scrapers (Plate XIX.) were not completed until the winter. They work very well, with a combined scraping and flushing action, and by their use the sand and gravel deposits can be moved from one end of the sewer to the other. The sludge-tank was filled a second time, principally with clear sand, when operations were stopped by the harbor's freezing over. The bay remained closed by ice until early in March, when the removal of the deposits was again resumed. It seems probable that this method of removal will prove as satisfactory as any which could be adopted.

As the tunnel is 142 feet below the harbor, and has been constantly full of sewage since pumping began, there has been no opportunity for inspecting it. For the first few months of 1884, before all of the city sewers had been intercepted, a comparatively small amount of sewage was pumped, especially at night. At such times the velocity of flow through the tunnel was very slight, often less than one-half of a foot a second. Occasionally pumping would be stopped for a few hours at night, to allow the sewage to accumulate. At present the ordinary flow in the tunnel is seldom faster than one foot a second. As the sewage takes from two to four hours to pass through the tunnel, at these slow velocities, it was to be expected that deposits would occur there.

To ascertain the extent of such deposits, and whether they were likely to become permanent, some experiments were made. These were based upon the following laws: —

That the flow through the tunnel is produced by the difference in elevation of the water at its two ends;

That the amount of this difference is a measure of the frictional resistance which the tunnel opposes to the flow of the sewage;

That, in proportion as the water-way of the tunnel is obstructed by deposits, the resistance, and therefore the difference in elevation of the water at its two ends, will be greater than they would be if the tunnel was clean.

The method of making the experiment was as follows: —

The quantity of water passing through the tunnel was ascertained by pump measurement, with allowance for slip. The difference in elevation at the two ends of the tunnel was determined by means of sliding gauges, with knife-edges where they came in contact with the surface of the water.

The coefficient was then calculated for the formula

$$V = C\sqrt{RI} \text{ or } C = \frac{V}{\sqrt{RI}}$$

in which

V = Velocity in feet per second

R = Hydraulic mean radius $= \frac{\text{area}}{\text{wet perimeter}}$

I = Sine of inclination $= \frac{\text{head}}{\text{length}}$

C = A coefficient ascertained by experiment.

As the tunnel is circular, 7.5 feet in internal diameter, the value of R, corresponding to the full cross-sectional area, is 1.875 feet. Experiments on the flow of water in the Sudbury-river Conduit,[1] which was a brick structure like the tunnel, gave a coefficient corresponding to R = 1.875, of about 137. It was not anticipated that the coefficient found for the tunnel, even when it was clean, would be quite so large as that of the conduit; since the surface of the former is somewhat rougher, and some loss of head would be occasioned by changes in direction at bends and by obstructions at the east shaft.

It was also expected that the coefficient would vary somewhat with the velocity and with the dilution of the sewage. Under the most favorable circumstances, with the tunnel free from deposits, the coefficient would approximate 137, being that found by the experiments above mentioned.

The full area of the tunnel was used in determining the values of V and R. This assumed that the tunnel was clean. Should the coefficient be found to be much lower than that anticipated it would show that the aforesaid assumption was incorrect, and that the area of the tunnel was partly obstructed.

Whatever was the true value of the coefficient, its increase or decrease, as determined by successive experiments under the same conditions, would show whether the amount of deposit in the tunnel was becoming less or greater.

Arrangements are provided for flushing the tunnel by running four pumps simultaneously, salt water being admitted to the pump-wells to supply any deficiency of sewage. The volume pumped is generally at the rate of about 114,000,000 gallons per day, which give a velocity of about four feet per second through the tunnel.

The first flushing with four pumps was done June 12, 1884. Just previous to this time, by two measurements on different days, the loss of head through the tunnel was ascertained to be about .54 of a foot, and the values of C were found to be 80 and 82. On June 13, the day after flushing, an experiment, with the same conditions as those previously made, gave a loss of head of .30 of a foot, and a value of C = 110.

[1] Transactions of the American Society of Civil Engineers, Vol. XII., No. CCLIII.

This value was still too low to indicate an entirely clean tunnel, but showed that the water-way had been increased by a removal of a portion of the deposit by the flushing. This was known to be a fact, since the sludge scoured out by the flushing had been observed in the reservoir. Inspection showed that the deposit carried into the reservoir was of a very light nature, containing soft mud, horse-manure, water-logged match-ends, bits of lemon-peel, paper, and similar substances.

Beginning in June, 1884, flushing with four pumps has been done regularly about once a fortnight. At four different times measurements to determine the value of C have been made during the flushing. At such times the velocity of flow is high, and from 75 to 80 per cent. of the volume pumped is clean salt water, affording conditions favorable for obtaining a high coefficient. The values of C, derived from these several experiments, were as follows: —

June 12, 1884. $C = 129.$
Oct. 20, 1884. $C = 120.7.$
Jan. 15, 1885. $C = 146.3.$
Feb. 16, 1885. $C = 146.6.$

The last two experiments were made on days following periods when the quantity of sewage pumped had been unusually large, on account of rain and melting snow, which may account for the largeness of the coefficients. There may, also, have been some unusual slip in the valves. There can be little doubt, however, that at this time the water-way of the tunnel was not appreciably obstructed.

Since these were experiments on the flow through a large pipe they may have some general interest for engineers, and their details are given in the following table: —

NOTE. — Two experiments made since the first edition was printed give the following results: —

Aug. 28, 1885. $C = 117.8.$
Sept. 25, 1885. $C = 121.5.$

In these two experiments the quantity of water flowing was measured in the reservoir, the height of the sewage in the sewers being kept constant. In previous experiments the values of C were based upon pump measurement, with a small allowance for slip. During the week preceding the experiment of Oct. 20, trials were made to ascertain the slip of each pump, and the results obtained on that day are probably trustworthy. The results of the experiments of Jan. 15 and Feb. 16 are now known to be too large, the rubber valves of the pumps having begun to wear out at this time, causing a large slip.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
Number of Experiment.	Date of Experiment.	Length of Tunnel.	Diameter of Tunnel.	Loss of Head in Tunnel.	Loss of Head per Foot (I).	Hydraulic mean Radius (R).	Volume in cubic Feet per Second.	Mean Velocity (V).	Value of C in Formula. $V=C\sqrt{RI}$.	REMARKS.
1.	June 6, 1884,	7166 feet.	7.5 feet.	0.520 feet.	.00007256	1.875 feet.	41.06	0.929	79.95	Sewage.
2.	" 9, "	"	"	0.566 "	.00007894	"	44.08	0.998	82.00	"
3.	" 12, "	"	"	3.648 "	.0005091	"	176 24	3.988	129.05	20 to 25 per cent. sewage; 75 to 80 per cent. salt water.
4.	" 13, "	"	"	0.297 "	.0000414	"	42.64	0.965	109.66	Sewage.
5.	Oct. 20, "	"	"	4.165 "	.0005812	"	173.56	3.929	120.67	20 to 25 per cent. sewage; 75 to 80 per cent. salt water.
6.	Aug. 28, 1885.	"	"	3.975 "	.0005547	"	167.78	3.798	117.78	" "
7.	Sept. 25, "	"	"	3.680 "	.0005135	"	166.51	3.769	121.46	" "

NOTE. — In the first four experiments the quantities in column 5 are the total differences in elevation of the water surface at the two ends of the tunnel, less a correction for loss of head at entrance. In the remaining experiments the head, a short distance below the entrance to the tunnel, was taken, and no correction was required. The tunnel has one quarter-turn of 9.75 feet radius and one angle of $23\frac{1}{4}$ degrees. These increase the resistance somewhat. On the other hand, the farther end of the tunnel enlarges gradually as a diverging tube, which facilitates the flow.

The wooden flume between Squantum and Moon Island has been watched carefully during the past year. It was at first tight, but the effect of the summer's sun lying on one side of it tended to make the planks shrink and warp somewhat, so that leakage occurred in some places. These were stopped by tightening the bolts and wedges, and by fastening the corner bottom planks to the sides with lag screws. To guard against the sun the flume was given a second coat of paint. Putting a cheap roof over it would, doubtless, prolong the duration of its effective service.

When the sewage in the reservoir is low the flume runs about half-full. As the basins fill, the depth of flow increases until finally it runs entirely full, acting as a pipe. The ordinary velocity of flow is about three feet a second, or less as the depth increases. Twice a day, when the reservoir is flushed, as described later on, the current through the lower end of the flume attains the remarkable velocity of about seven feet a second. This velocity is sufficient to remove stones and brickbats.

Nevertheless the flume is not clean. From its bottom up to the ordinary flow line the sides are covered with a slimy deposit from one-eighth to one quarter of an inch in thickness. Above the middle and on the top there is also some slime, but not so much as below. The condition of this sewer is commended to the attention of those sanitarians who are accustomed to represent flushing as a certain remedy for the accumulation of slime in pipes.

Some experiments we made to determine the value of C in the formula $V = C\sqrt{RI}$ as applied to the flume. In one trial, the flume flowing about half-full with sewage, the value of R was 1.45 feet, the velocity was 2.94 feet a second, and the value of C was found to be 116.9. In a second trial, under similar conditions, the following values were obtained: $R = 1.41$; $V = 2.87$; $C = 116.6$. In a third trial, when four pumps were running and the flume was flowing full, 75 to 80 per cent. of the water pumped being clean salt water, the values of R, V, and C, respectively, were 1.5, 4.80, and 134.8. It will be noticed that the value of R was about the same in the last trial as in the first two, but that the value of C was very much greater. It is thought that this may be due to the fact that the first trials were made with clear sewage, whereas, in the case of the last trial, the water was comparatively clean. It seems reasonable to suppose that some head would be expended in maintaining in suspension the solid particles contained by the sewage. The subject is worthy of further investigation, it because concerns the applicability to the flow of sewage of hydraulic formulæ derived from experiments on the flow of clean water.

The reservoir has a capacity of 25,000,000 gallons. As sewage is stored in it for about ten hours at a time, between the end of one period of discharge and the beginning of another, the basins, as a rule, have been filled only about half-full during the past year. The process of discharging is begun about one hour after the beginning of ebb tide. By this time the surface of the sea is as low as the bottom of the reservoir, and a good harbor current is setting outwards past the outlet. Water is admitted to the turbine, and by the power transmitted from it the upper gates in the outfall sewer are first closed. The sewage then arriving is thus stored in the sewer, and its surface rises several feet. Meantime the lower gates in the discharge sewer are opened, and the sewage in the reservoir flows through them to the outlet. Under ordinary circumstances the basins are emptied in about thirty minutes.

There is left in the basins a thin deposit of semi-fluid mud, generally about one-quarter of an inch thick, but in greater quantity after storms. To remove this, flushing is first resorted to. During the past year four brick partition-walls were built across the gallery between the sewers and the reservoir. One of these was built opposite the middle of each basin. As soon as a basin is empty an upper gate is opened on one side of the dividing wall just mentioned, and the lower gates on the other side of it. The sewage, which has by this time accumulated to a considerable depth in the outfall sewer, passes through the openings into one side of the basin, and flows with moderate force up the gutters to the back retaining-wall. As the gutters fill the sewage overflows across the ridges and down the gutters on the other side of the basin. Much of the sludge is in this way washed off into the gutters and carried into the discharge sewers. The flushing is done alternately from one and the other side of the basin.

If a basin cannot thus be entirely cleaned men descend into it with broad wooden scrapers, convex on one side, to fit the gutters, and flat on the other. With these the mud is scraped into the gutters and pushed down into the gallery, whence it is washed out into the sea at the next time of discharge. Such cleansing operations occupy about one-half hour for each basin, and are not especially disagreeable for the men.[1]

When the sides of a basin need cleaning the pump in the engine-house is started, and one or more lines of hose are coupled to the hydrants on the 4-inch pipe fastened to the floor in the middle of each basin. The pump will give two strong fire streams with sufficient force to wash off any crust which has hardened on the walls. The streams can also be used in connection with scraping and washing the floors of the basin.

The first sewage which discharges at the outlet contains a considerable amount of sludge which has settled in the gallery and discharge sewers, and gives to the effluent a dark, muddy appearance. After a few minutes the color is somewhat lost, and the effluent looks like moderately dirty water.

Its effect in discoloring the salt water, and its course as it joins the current out of the harbor, can be plainly noticed. Being fresh water it rises to the surface, and when a half-mile from the outlet seems to lie on top of the salt water in a stratum but a few inches thick. The greasy nature of the sewage tends to quiet the ripples commonly seen on the surface of the harbor, so that the area affected by the discharge is plainly determined. From experiments with floats it is known that the sewage travels nearly five miles, following the Western Way and Black-Rock Channel out to the vicinity of the Brewster Islands. By the time it has travelled a mile from the outlet most of the color is lost, and by the time it has gone two miles (before passing Rainsford Island) not the slightest trace of it can be distinguished.

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[1] Since this was written slight changes have been made in the method of flushing the floors and gutters, which render the operation so effective that it is no longer necessary to send men into the basins to clean them.

When the works went into operation, and for the first nine months thereafter, there were no gates near the outlet at the end of the discharge sewers. As a consequence the last portion of sewage from the reservoir, filling the discharge sewers, flowed out into the harbor slowly as the tide fell. This was the dirtiest part of the sewage, because it contained scourings from the basins. By referring to the plan (Plate V.) it will be seen that a cove was formed between the island and the pier containing the discharge sewers. In this cove a foot or more of sludge accumulated. A thin layer of sludge also formed on the beach between the outlet and the extreme point of the island. This last-named deposit was only found between the levels of the mid-tide and low water.

In winter no smell comes from these deposits, and in summer none is noticed except during low tide. On three occasions last summer, when the wind was from the east, the smell was so strong as to be noticed at Squantum, a mile away.

In hopes of preventing, or at least lessening, the formation of such deposits, a set of gates have been placed in the chamber at the outlet. By these the sewage filling the discharge sewers is held back until the beginning of the succeeding discharge, when it is forced out into a good current. These gates have not been in place long enough to show how much they will accomplish; but, should objectionable deposits still continue to form on the island, it is thought that an effectual remedy can be provided. This will consist in building a solid bulkhead wall near the line of low water, from the outlet to the extreme easterly point of the island. Such a structure could be built for $30,000.

No trace of the sludge has been found on the shores in any other part of the harbor. Very little smell emanates from the reservoir in cool weather; not enough to be perceptible at a contractor's boarding-house, about 200 feet distant. In summer the smell is more noticeable; but not nearly so much so as is that arising from the deposits of sludge on the beach.

As a whole the Main Drainage System works well, and no radical defect has been detected in any portion of it. It is not claimed that, by itself it furnishes a perfect system of sewerage for the city. Many defective house-drains and common sewers still exist, and must in time be replaced; but the new system provides an outlet for the rest, without which other reforms would be comparatively useless.

By building the Main Drainage Works Boston has taken the first, most essential step in the direction of efficient sewerage.

APPENDIX.

APPENDIX A.

RECORD OF TESTS OF CEMENT MADE FOR BOSTON MAIN DRAINAGE WORKS.

1878–1884.[1]

The Main Drainage Works chiefly consist of brick, stone, and concrete masonry. Abut 180,000 barrels of cement were required to build this masonry; and to insure its stability and durability it was necessary that the cement should be of good quality. From the start, therefore, means for determining the qualities of all cements used or offered for use were provided. A room was set apart for these operations and an inspector appointed to conduct them.

The tests were devised, principally, in order to determine three points, namely: —

1. The relative strength and value of any cement as compared with the average strength and value of the best quality of similar kinds of cements.

2. The absolute and comparative strength and value of mortars of different kinds made from the same cement.

3. The effect produced upon the strength of any cement-mortar by different conditions and methods of treatment.

This knowledge was chiefly sought by observations of the tensile strength of the cements and mortars tested. Reasons for adopting the tensile test were, that it required comparatively light strains to produce rupture; that, as it was universally used, it afforded results which could be compared with those of other observers; and, finally, because the tensile stress is precisely that by which the mortar of masonry, in most cases of failure, actually is broken.

All the particles of any cement are of appreciable size, and its strength as a mortar depends on the extent to which the particles adhere, at their points of contact, to each other or to some inert substance. This adherence may be overcome and the mortar broken, either by pulling the particles apart by tension, or by pushing them past each

[1] A paper presented to the American Society of Civil Engineers.

other by compression. The effect upon the adhering quality of the particles is not very different in the two operations; but in the latter the friction of the particles against each other must also be overcome, which requires the application of very much more force. Transverse tests are only tensile tests differently applied, and shearing produces a stress intermediate to tension and compression. When masonry is strained one part of it is in tension, another in compression, and, as mortar yields more readily to tensile stress, failure generally occurs by rupture of the joints in tension.

Briquettes for testing, with a breaking section of one square inch, were first used; but it was thought that these, from their small size, were liable to be strained and injured by handling in taking them from the moulds and transferring them to the water. A larger pattern, with a breaking section one and one-half inches square, or two and one-quarter square inches, was finally adopted. Comparative tests with briquettes of one inch and two and one-quarter inches section respectively indicated that there was little, if any, difference in their strength per square inch.

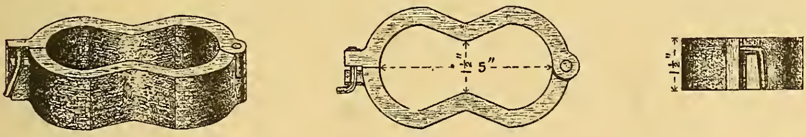
The shape of the briquette adopted is shown by Fig. 2, Plate XXVIII. Fig. 1 of the same plate shows the brass moulds in which the mortar was packed to form the briquettes. These moulds proved very satisfactory. They were strong, and easily clamped and opened. The clamp consisted of a piece of brass wire riveted loose in the projecting lug of one branch of the mould, and binding by friction when turned against the wedged-shaped lug on the other branch. If a fastening worked loose a single tap of the hammer would tighten it. All breaking loads were reduced to pounds per square inch of breaking section by multiplying by four and dividing by nine.

Before testing a cement its color was first observed. The absolute color of a natural cement indicates little, since it varies so much in this particular. But, for any given kind, variations in shade may indicate differences in the character of the rock or in the degree of burning. With Rosendale cements a light color generally indicated an inferior or underburned rock. An undue proportion of underburned material was indicated in the case of Portland cement by a yellowish shade, and a marked difference between the color of the hard-burned, unground particles retained by a fine sieve and the finer cement which passed through the sieve.

The weight per cubic foot was also sometimes ascertained. As this would vary with the density of packing, a standard for comparison was adopted, which was the density with which the cement would pack itself by an average free fall of three feet. The apparatus used

BRASS MOULD.

FIG. 1.



BRIQUETTE.

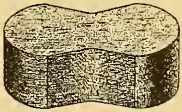


FIG. 2.

PAT OF CEMENT
TESTED FOR CHECK CRACKS.

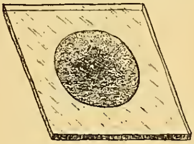


FIG. 4.

TUBE AND BOX
FOR WEIGHING CEMENT.

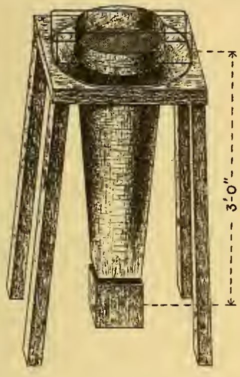


FIG. 3.

LIGHT & HEAVY WIRES.

FIG. 5.

PAN FOR KEEPING BRIQUETTES.

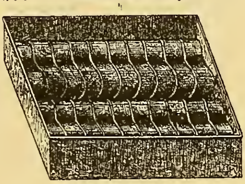
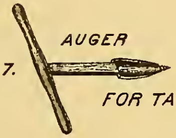


FIG. 6.

AUGER

FIG. 7.



SCOOP

FIG. 8.

FOR TAKING SAMPLES FROM BARRELS.

BARREL OF CEMENT
60 PER CENT FINE

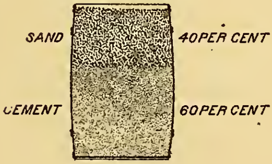


FIG. 9.

BARREL OF CEMENT
90 PER CENT FINE

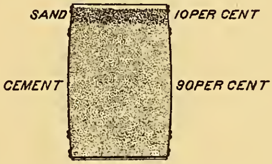


FIG. 10.

is shown by Fig. 3, Plate XXVIII. The cement was placed in a coarse sieve on the top of a galvanized iron tube, and, the sieve being shaken, the cement sifted through the tube into the box below. This box held exactly one-tenth of a cubic foot when struck level with its top.

The weights per cubic foot as determined by this method varied considerably with different kinds and brands of cement, and somewhat with different samples of the same brand. The averages were as follows: —

Table No. 1.

Rosendale	49 to 56 pounds.
Lime of Teil	50 "
Roman	54 "
A fine-ground French Portland	60 "
English and German Portlands	77.5 to 87 "
An American Portland	95 "

The following table shows the effect of fine grinding upon the weight of cement. It gives the weight per cubic foot of the same German Portland cement, containing different percentages of coarse particles, as determined by sifting through the No. 120 sieve: —

Table No. 2.

0 per cent. retained by No. 120 sieve — W't per cubic foot	75 pounds.
10 " " " " " "	79 "
20 " " " " " "	82 "
30 " " " " " "	86 "
40 " " " " " "	90 "

It was soon discovered that there was no direct ratio between weight and strength. As a general rule, subject to exceptions, heavy cement, if thoroughly burned and fine-ground, was preferred to light cement. Fine-ground cements were lighter than coarse-ground and underburned rock lighter than well-burned. While color and weight by themselves indicated little, yet, considered together and also in connection with fineness, they enabled the inspector to guess at the character of a cement, and suggested reasons for high or low breaking. A cement which was light in color and weight, and also coarse-ground, would be viewed with suspicion.

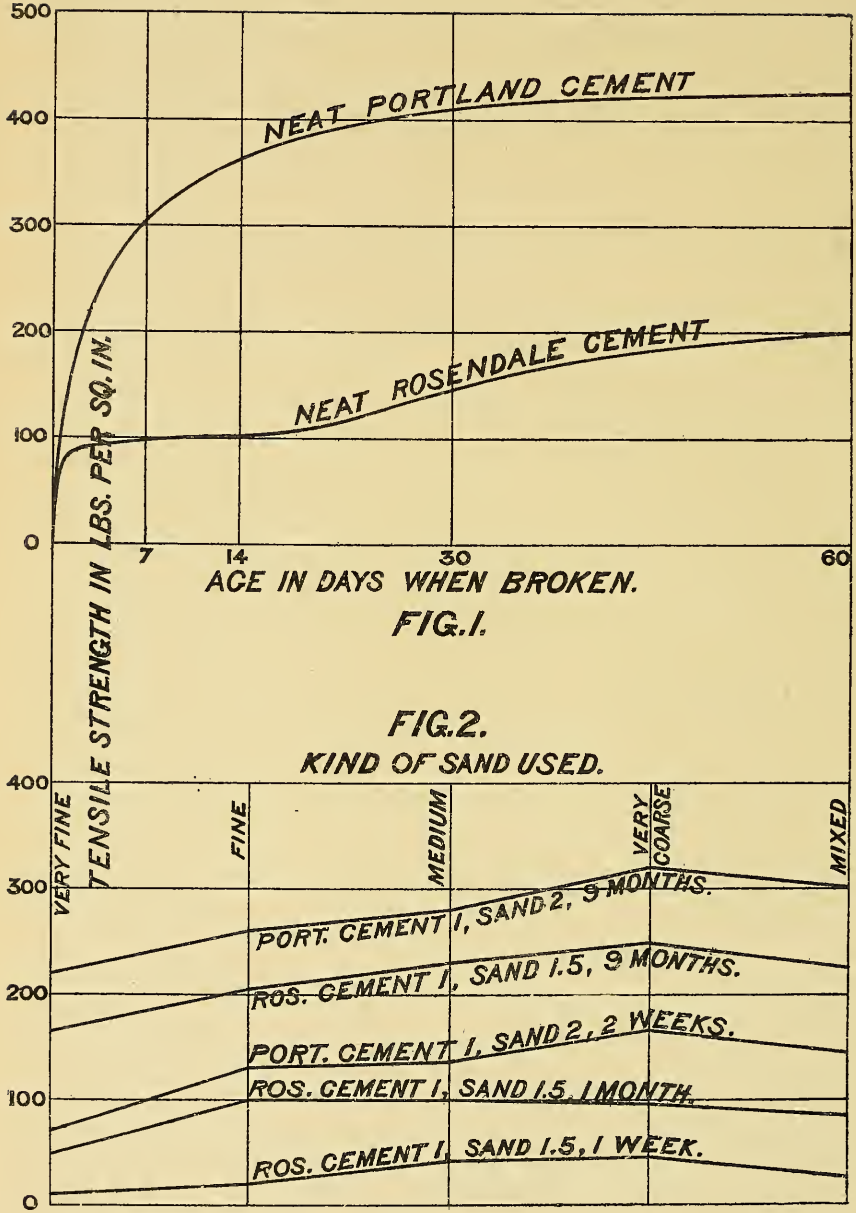
The test of fineness, which followed, was considered of great importance, as showing the quantity of actual cement contained in a barrel, and its consequent value. Small scales were used, made for this purpose by Fairbanks & Co. One-quarter of a pound of the sample was weighed out and passed through the sieve. The coarse particles retained by the sieve were returned to the scales, whose balance-beam carried a movable weight, and was graduated in percentages of one-quarter pound. The percentage of coarse particles retained by the sieve could thus be read directly from the beam.

Standard sieves, varying from No. 50 to No. 120, were used. The number of meshes to the lineal inch in any sieve is commonly supposed to correspond with its trade number. As sold, however, they vary somewhat, and the number of wires is generally less, by about ten per cent., than the number of the sieve. A No. 50 sieve commonly has about 45 meshes to the inch, and a No. 120 about 100, or a few more. In important contracts, where a certain degree of fineness was called for, it was customary carefully to compare two sieves and retain one, which was specified as the standard, while the other was delivered to the manufacturer for his guidance.

In accordance with common practice the No. 50 sieve was first used. It was soon discovered, however, that so coarse a sieve did not always give a correct indication of the fineness of the cement. This was especially true of Portland cements. Some brands, chiefly German, were evidently bolted by the manufacturers with special reference to tests by this sieve, in which they would leave no residuum. Yet the bulk of such cements, while containing no very coarse particles, might prove quite coarse when tested by the No. 120 sieve.

It is obvious that pieces of burned cement slag one-fourth of an inch in diameter would have no cementing quality, and the same is true of particles one one-hundredth of an inch in diameter. At precisely what smaller size the particles begin to act as cement it was impossible to determine. Those retained by a No. 120 sieve, in which the open meshes are approximately one two-hundredth of an inch square, were found to have some slight coherence, even after washing to remove the finer floury cement which was sticking to them. It was also found that the No. 120 sieve was about as fine a one as it was practicable to use, on account of the time required to sift the cement through it. It was, therefore, adopted as a standard.

Assuming (what was only approximately verified by experiments on tensile strength) that only what passed through this sieve had real value as cement, and that the rest was not very different from good, sharp sand, the difference in the quantity of actual cement obtained in purchasing barrels 60 and 90 per cent. fine, respectively, is shown


500
400
300
200
100
0
NEAT PORTLAND CEMENT
NEAT ROSENDALE CEMENT
TENSILE STRENGTH IN LBS. PER SQ. IN.
7
14
30
60
ACE IN DAYS WHEN BROKEN.
FIG.1.
FIG.2.
KIND OF SAND USED.
VERY FINE
FINE
MEDIUM
VERY COARSE
MIXED
PORT. CEMENT 1, SAND 2, 9 MONTHS.
ROS. CEMENT 1, SAND 1.5, 9 MONTHS.
PORT. CEMENT 1, SAND 2, 2 WEEKS.
ROS. CEMENT 1, SAND 1.5, 1 MONTH.
ROS. CEMENT 1, SAND 1.5, 1 WEEK.

by Figs. 9 and 10, Plate XXVIII. This has an important bearing on the proportion of sand to be added in practical use; for when mortar is mixed for use in the proportion of one barrel of cement to two of sand, if there be nine parts of cement and one of sand in the barrel of cement itself, the actual proportion in the mortar will be .9 to 2.1 or 1 to 2.33. If there be only six parts of cement and four of sand in the barrel of cement the resulting proportion in the mixture will be .6 to 2.4 or 1 to 4.

Fine cement can be produced by the manufacturers in three ways: by supplying the mill-stones with comparatively soft, underburnt rock, which is easily reduced to powder; by running the stones more slowly, so that the rock remains longer between them; or by bolting through a sieve and returning the unground particles to the stones. The first process produces an inferior quality of cement, while the second and third add to the cost of manufacturing.

The extra cost, as estimated by a firm of English manufacturers, of reducing a Portland cement from an average of 70 per cent. fine, tested by No. 120 sieve, to 90 per cent. fine, was 18 cents per barrel. The price at which 5,000 barrels of their ordinary make, 70 per cent. fine, were offered, delivered on our work, was $2.82 per barrel. The same cement, ground 88 per cent. fine, was delivered for $3 a barrel. On the foregoing assumption of the value of fine and coarse particles the city, by accepting the first offer, would have obtained in bulk 3,500 barrels of actual cement and 1,500 barrels of sand for $14,100. By accepting the second offer it obtained in bulk 4,400 barrels of cement and 600 of sand for $15,000; that is, the 900 additional barrels of cement cost $1 a barrel. Experiments illustrating the value of fine grinding, and further comments, will be given later.

Tests were made both of neat cement and of cement mixed with sand in different proportions. The latter were preferred, because they showed the strength and value of the mortars used in actual work. It was found also that the strength of briquettes made of neat cements did not always indicate the capacity of these cements to bind sand, or the strength of the mortars made with them. This is illustrated by experiment No. 10, on page 127.

The greater the proportion of sand in the mortar tested the more accurately was the actual cementing quality of the cement indicated. As, however, very weak mixtures took a long time to harden, and were liable to injury from handling, one part cement to three parts sand was adopted as the usual mixture for testing Portland cements, and one to one and one-half or two for American cements. Occasionally when testing large quantities of some well-known brand, the object being to see that a uniform strength was maintained, it was found sufficient, and simpler, to omit the sand and make the briquettes of cement only.

In making mortars for testing, rather coarse, clean, sea-beach sand was used.

The subsequent strength of the briquettes depended largely upon the amount of water with which they were gauged. The highest results were obtained by using just enough water thoroughly to dampen the cement, giving the mass the consistency of fresh loam, which became pasty by working with a trowel. For ordinary testing sufficient water was added to make a plastic mortar, somewhat stiffer than is commonly used by masons. Different cements varied in the amounts of water needed to produce this result. As a rule American cements needed more water than Portland, fine ground more than coarse, and quick-setting more than more slow-setting cements. Experiment No. 9, page 127, shows the comparative strength of mortars gauged with different percentages (in weight of the cement) of water. The standard adopted was 25 per cent. for Portland cement and 33 per cent. for Rosendale; but these amounts were increased or diminished by the operator to suit the circumstances, his aim being to obtain mortars of unvarying consistency.

The way in which the test briquettes were made was as follows: the moulds, having been slightly greased inside to prevent the mortar sticking to them, were placed on a polished marble slab. This support for them was used because it was easily cleaned and the mortar did not stick to it. Experiment No. 6, page 124, shows that the use of porous or of non-porous beds to support the moulds does not materially affect the strength of the mortars. The requisite amounts of cement and sand for one briquette were weighed out and incorporated dry in a mixing-pan. The proper amount of water was also weighed out and added, and the mass worked briskly with a small trowel until of uniform consistency. A brass mould was half filled with the mortar, which was rammed into place by the operator with a small wooden rammer, in order to displace any bubbles of air which might be confined in it. The mould was then filled to its top with the remaining mortar, which was in turn rammed down. Finally the mortar was struck even with the top of the mould and given a smooth surface by the trowel.

The amount of mortar packed in the mould, and the consequent density of the briquette, would vary with any variation in the degree of force exerted by the operator in ramming. This variation was reduced to a minimum by always mixing a fixed amount of mortar, which was barely more than sufficient to fill one mould. Irregularities in ramming would thus be detected by variations in the amount of surplus mortar, and could be checked. An attempt was made to do away wholly with this element of uncertainty by pressing the mortar into the moulds with certain fixed pressures. Apparatus was devised and used for this purpose, but was finally abandoned on account of the length of time required for its use.

The initial energy of the cement — that is, the length of time after mixing before it "set" — was determined by noting the length of time before it would bear "the light wire" of $\frac{1}{12}$ inch in diameter loaded with $\frac{1}{4}$-pound weight, and also "the heavy wire" $\frac{1}{24}$ inch in diameter loaded with 1-pound weight. At the former time the cement was said to have begun to set, and at the latter it was entirely set. Different kinds and brands of cement varied greatly in the time after mixing when they would bear the wires. Some brands of English Roman cement would set in two minutes, and some of Portland required over 12 hours. Cold retarded the setting, and fresh-ground cements set quicker than older ones. No direct relation was established between initial energy and subsequent strength. By judicious mixing of quick and slow setting cements a mixture could be obtained which would set within any desired period.

As soon as the briquettes were hard enough to handle without injury, which, with different cements and mixtures, varied from five minutes to twelve or more hours, they were removed from the moulds and placed in numbered pans filled with water. Before removal each briquette had marked upon it, with steel stamps, the name of the cement, date of mixing, and a number by which it could be further identified. The inscription might read thus: —

"Alsen 1–3. May 17, 1880. 47."

Records were also kept in books and on blanks provided for the purpose. The briquettes were kept in the pans, covered with water, until they were broken. Their age when broken varied from 24 hours to five years.

In testing a well-known American cement, of generally uniform quality, if it were an object to save time, the comparative excellence of the samples could be sufficiently determined by a 24 hours' test of briquettes made of neat cement. Under similar conditions neat Portland cement could be tested in seven days. To test mortar of either kind of cement took a week, or, better, a month; especially if there was a liberal proportion of sand.

The probable value of an untried brand of cement could hardly be ascertained with certainty in less than a month, and not always then. To illustrate the occasional need of long-time tests, a case may be cited.

A new brand of cement, made by some patent process, was offered for use on the work. When tested it set up well, and at the end of a week the neat cement had a tensile strength of 184 pounds per square inch. In a month this had increased to 267 pounds, indicating a strength equal to that of a low-grade Portland cement. At this time there was nothing in the appearance of the briquettes to indicate any weakness. Yet, after about six months, they fell to pieces, and had entirely lost their cohesive quality.

The briquettes were broken by a machine made for the Department by Fairbanks & Co. It worked with levers, acting on a spring balance, which was tested from time to time, and found to maintain its accuracy.

During the progress of the work the following brands of cement were submitted for approval, and were tested with more or less thoroughness: —

Old Newark, Newark and Rosendale, Norton, Hoffman, Old Rosendale, New York and Rosendale, Lawrenceville, Rosendale, Arrow, Keator, Howe's Cave, Rock Lock, Buffalo, Cumberland, Round Top, Selenitic, Vorwholer, Star, Dyckerhoff, Alsen, Hemmor, Bonnar, Onward, Burham, J. B. White, Knight, Bevan & Sturge, Brooks, Shoobridge & Co., Leavitt, Grand Float, Diamond, Spanish, Red Cross, La Farge, Lime of Teil, Saylor, Coolidge, Walkill, Cobb, Abbott.

The following is a record of the more instructive tests made for experimental purposes. Nearly all of them were made with special reference to the work then in hand to elucidate some practical questions affecting the purchase, testing, or use of the cements needed for building purposes. The names of the brands of cement tested in the several experiments are generally omitted. This is in order to avoid any unwarranted use of the results as recorded.

The figures given in the tables always represent average breaking loads in pounds per square inch of breaking section.

Experiment No. 1.

Of natural American cements the Rosendale brands (so called) are the only ones which find a sale in the Boston market, and they were chiefly used on the work. Imported Portland cements were also largely used. It was important, therefore, to ascertain the actual and comparative strengths of these cements. The following table gives results compiled from about 25,000 breakings, of 20 different brands, and fairly represents the average strength of ordinary good cements of the two kinds. Some caution, however, is necessary in using the table as a standard in which to compare other cements. Quick-setting cements might be stronger in a day or week, and show less increase in strength with time. Fine-ground cements would probably give lower results tested neat, and higher ones with liberal proportions of sand.

TABLE No. 3.

ROSENDALE CEMENT.

NEAT CEMENT.					CEMENT, 1; SAND, 1.				CEMENT, 1; SAND, 1.5.				CEMENT, 1; SAND, 2.				CEMENT, 1; SAND, 3.				CEMENT, 1; SAND, 5.			
1 Day.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.
71	92	145	282	290	56	116	190	256	41	95	155	230	24	60	125	180	14	35	80	121	5	16	46	80

PORTLAND CEMENT.

NEAT CEMENT.					CEMENT, 1; SAND, 1.				CEMENT, 1; SAND, 1.5.				CEMENT, 1; SAND, 2.				CEMENT, 1; SAND, 3.				CEMENT, 1; SAND, 5.			
1 Day.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.
102	303	412	468	494	160	225	347	387	...	...	...	...	126	163	279	323	95	140	198	257	55	88	136	155

The table is instructive in several ways. It shows that Portland cement acquires its strength more quickly than Rosendale; that both cements (but especially Rosendale) harden more and more slowly as the proportion of sand mixed with them is increased; that, whereas neat cements and rich mortars attain nearly their ultimate strength in six months or less, weak mortars continue to harden for a year or more. The table shows the advantage of waiting as long as possible before loading masonry structures, and the possibility of saving cost by using less cement when it can have ample time to harden. It also shows that Portland cement is especially useful when heavy strains must be withstood within a week.

Experiment No. 2.

These series of tests are like the preceding ones, except that a single brand of cement was used in making each. The average breaking loads per square inch were obtained from a less number of briquettes (about 500 in all) ; mortars with larger proportions of sand were included in the series, and the tests were extended for two years.

Table No. 4.

PORTLAND CEMENT MORTAR.

Age when Broken.	Neat Cement.	Cement, 1; Sand, 2.	Cement, 1; Sand, 4.	Cement, 1; Sand, 6.	Cement, 1; Sand, 8.	Cement, 1; Sand, 10.	Cement, 1; Sand, 12.
One week .	295	166	89	50	33	23	17
One month .	341	243	132	88	67	50	41
Six months .	374	343	213	149	98	76	51
Two years .	472	389	226	159	98	49	31

ROSENDALE CEMENT MORTAR.

Age when Broken.	Neat Cement.	Cement, 1; Sand, 2.	Cement, 1; Sand, 4.	Cement, 1; Sand, 6.	Cement, 1; Sand, 8.	Cement, 1; Sand, 10.	Cement, 1; Sand, 12.
One week .	. . .	24	7	5	. . .	. . .	. . .
One month .	. . .	83	33	17	8	5	. . .
Six months .	. . .	172	93	62	50	33	21
Two years .	. . .	211	90	56	33	22	20

The tables show that considerable strength is acquired in time, even when a very large proportion of sand is used ; also, that most mortars increase very little, if any, in tensile strength after six months or a year. They become harder with time, but also become more brittle and probably less tough. Specimens of mortar two years old, or more, break very irregularly.

Experiment No. 3.

The rate at which Rosendale and Portland cements, respectively, increase in strength during the first two months after mixing is very different, and has some bearing on their use, and more on the interpretation of tests of them made within that period. The curves (Fig.

1, Plate XXIX.), which indicates this rate of increase, were compiled from tests with neat cement. It is probable that tests with mortar would give somewhat similar results. By comparing the two curves it appears that after 24 hours Rosendale cement has about three-fourths of the strength of Portland. While the latter increases greatly in hardness during the next few days, the energy of the former becomes dormant, so that at the end of a week the Portland cement is more than three times as strong as the Rosendale. During the second week the Portland cement increases more slowly, and the Rosendale continues nearly quiescent. At about this period, and for the next six weeks, the Rosendale cement gains strength, not only relatively, but actually faster than the Portland, so that when two months old the former has one-half the strength of the latter. After two months the relative rate of increase and the comparative strength of the two cements remain nearly unchanged. A series of tests with a Buffalo cement, and one with a Cumberland cement, gave results similar to those with Rosendale cement.

Experiment No. 4.

For making tests it is not always convenient to obtain sand of uniform size, and still less so to obtain such sand in sufficient quantities for use in work. The curves (Fig. 2, Plate XXIX.) record some tests made to determine the effect of fineness and of uniformity of size in sand upon the strength of mortars made with it.

The curves show that for comparative tests it is advisable to have sifted sand of nearly uniform size; that mortars made with coarse sand are the strongest, and that the finer the sand the less the strength. It also appears that mixed sand, *i.e.*, unsifted sand containing a mixture of particles from coarse to fine, makes nearly as strong a mortar as coarse or medium coarse sand. For use in work, therefore, it is well to avoid fine sands; but it is not necessary to have sand of uniform size, or to sift out a moderate proportion of fine particles.

Experiment No. 5.

As some experimenters on cement use a test briquette with a breaking section of 1 square inch, and others one with a section of $2\frac{1}{4}$ square inches, the following experiment was made to determine the difference, if any, in the strength acquired by the same mortars moulded into briquettes of these different sizes. Two series of tests were made, in the same way, with the same mortars. In one series the briquettes had a breaking section of 1 square inch, and in the other the section was $2\frac{1}{4}$ square inches. The results are given in the following table, in which the figures represent breaking loads in pounds per square inch, and are averages from five breakings: —

TABLE No. 5.

	Rosendale Cement.							Portland Cement.					
	Neat Cement.				Cement, 1; Sand, 1.5.			Neat Cement.			Cement, 1; Sand, 1.5.		
	1 Day.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.
1-inch Section	49	83	156	286	27	53	236	309	460	657	60	96	175
$2\frac{1}{4}$-inch Section	49	78	173	258	27	62	311	347	391	578	67	108	230

As is usual, the breaking loads are somewhat irregular, the inch section excelling at some points and the larger section at others. The experiment, however, seems to indicate that neither size will, as a rule, give higher results than the other.

EXPERIMENT No. 6.

Some experimenters have thought it important to place the moulds in which the mortar is packed for testing upon a porous bed, such as blotting-paper or plaster. Others use a non-porous bed of glass, slate, or marble. The following series of tests were made to discover the effect of these different modes of treatment. The figures in the tables represent breaking loads, in pounds, per square inch, and are averages of about ten breakings: —

TABLE No. 6.

ROSENDALE CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Neat . . .	Marble . .	95	151	228	325
	Plaster . .	106	178	303	316
Cement, 1 . .	Marble . .	44	107	210	251
Sand, 1.5 . .	Plaster . .	62	120	219	265

A CUMBERLAND CEMENT.

Mixture.	Kind of Bed.	One Day.	One Week.	One Month.	Six Months.	One Year.
Neat . . .	Marble . . .	128	133	142	231	241
	Plaster . . .	147	165	176	244	257
Cement, 1 . .	Marble . . .	. . .	107	161	275	339
Sand, 1.5 . .	Plaster . . .	. . .	128	166	299	345
Cement, 1 . .	Marble . . .	. . .	85	134	201	292
Sand, 2 . . .	Plaster . . .	. . .	111	148	241	294
Cement, 1 . .	Marble . . .	. . .	40	94	162	163
Sand, 4 . . .	Plaster . . .	. . .	46	91	164	170

GERMAN PORTLAND CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Cement, 1 . .	Marble . .	259	367	390	. . . .
Sand, 1 . . .	Plaster . .	213	376	411	. . . .
Cement, 1 . .	Marble . .	176	256	346	345
Sand, 2 . . .	Plaster . .	196	258	326	357
Cement, 1 . .	Marble . .	141	225	250	313
Sand, 3 . . .	Plaster . .	147	220	258	312
Cement, 1 . .	Marble . .	103	157	240	274
Sand, 4 . . .	Plaster . .	120	150	233	264
Cement, 1 . .	Marble . .	82	108	182	213
Sand, 5 . . .	Plaster . .	103	140	193	197

Making allowance for a few irregularities, it appears from the foregoing tables that the use of a porous bed gives slightly higher results for the first one or two months, but that the difference disappears or becomes insignificant with age.

Experiment No. 7.

It is a well-recognized fact that in experimenting with cements, even when great care is exercised, individual specimens break very irregularly, and that results even approximately conforming to theory can only be obtained from averages from a large number of breakings. The personal equation of the operator, and the degree of force with which he presses the mortar into the moulds, is one factor in producing irregular results. To do away with this a machine for packing the moulds was devised and used for a time. By this the mortar was pressed into the moulds by a metallic plunger, acting with definite pressures, varying from 50 to 400 pounds.

The machine-made briquettes broke with somewhat greater uniformity than hand-made ones. So much more time was required to make briquettes with this machine that it was found to be impracticable to employ it for general use.

Experiment No. 8.

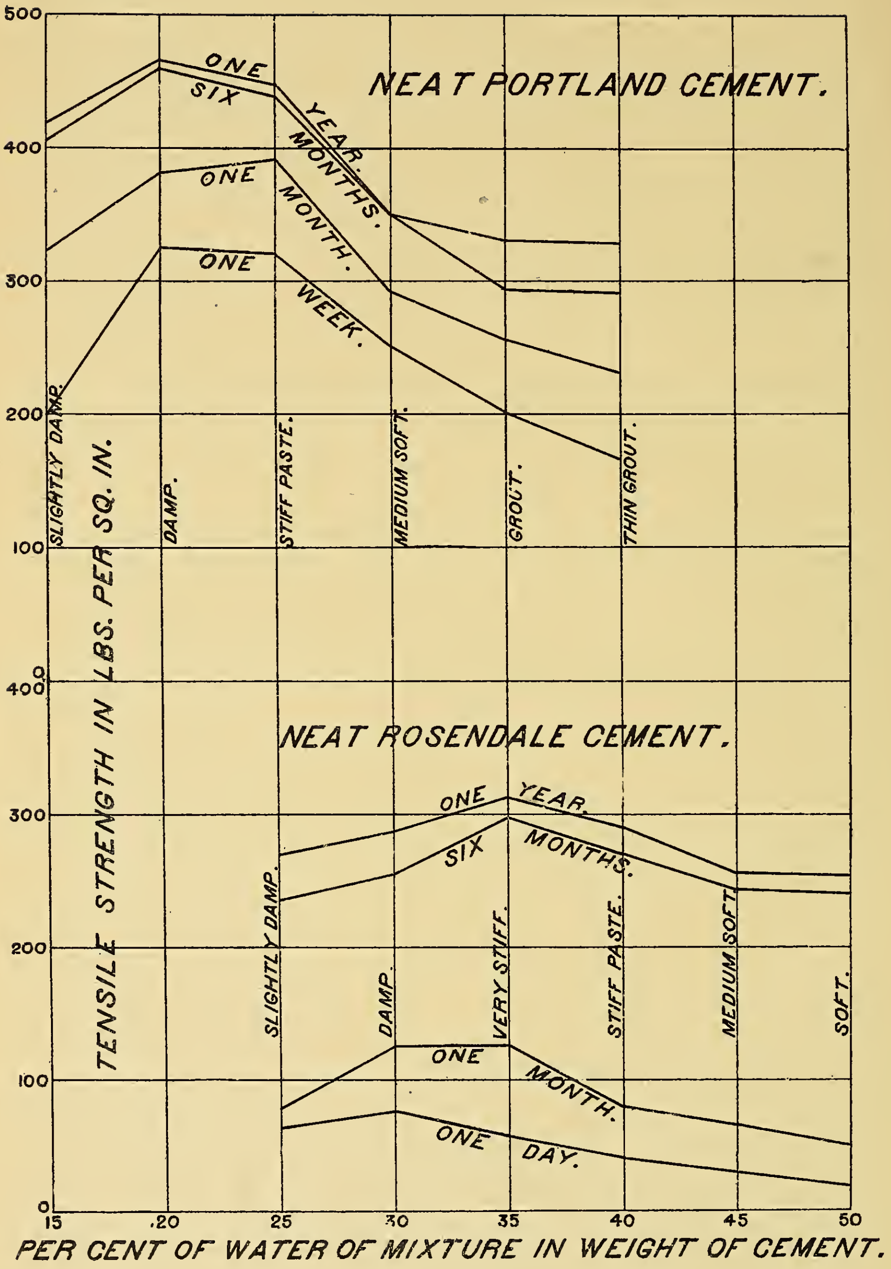
By the sea it is frequently convenient to mix mortar with salt-water. Brine is also used in winter as a precaution against frost. This experiment was made to obtain the comparative effect of mixing with, and immersing in, fresh and sea water respectively. The tests were made upon a Rosendale mortar, mixed one part cement to one part sand, and an English Portland mortar, one part cement to two parts sand. The figures are averages of about ten breakings, and give the tensile strength in pounds per square inch with the different methods of treatment and at different ages.

Except for some irregularity in the breakings for one year (which may have been due to the manipulation), the table indicates that salt, either in the water used for mixing or that of immersion, has no important effect upon the strength of cement. Salt-water retards the first set of cement somewhat.

Table No. 7.

Rosendale Cement Mortar, 1 to 1.					Portland Cement Mortar, 1 to 2.			
Fresh Water.	Fresh.	Salt.	Salt.	Mixed with.	Fresh.	Fresh.	Salt.	Salt.
Fresh Water.	Salt.	Fresh.	Salt.	Immersed in.	Fresh.	Salt.	Fresh.	Salt.
40	48	50	61	One week .	151	122	152	149
126	135	114	126	One month .	213	191	203	200
247	250	243	224	Six months .	314	245	277	264
310	263	224	217	One year .	342	231	346	295

PLATE XXX



NEAT PORTLAND CEMENT.
ONE YEAR.
SIX MONTHS.
ONE MONTH.
ONE WEEK.
SLIGHTLY DAMP.
DAMP.
STIFF PASTE.
MEDIUM SOFT.
GROUT.
THIN GROUT.
NEAT ROSENDALE CEMENT.
ONE YEAR.
SIX MONTHS.
ONE MONTH.
ONE DAY.
SLIGHTLY DAMP.
DAMP.
VERY STIFF.
STIFF PASTE.
MEDIUM SOFT.
SOFT.
TENSILE STRENGTH IN LBS. PER SQ. IN.
500
400
300
200
100
0
400
300
200
100
0
15
.20
25
30
35
40
45
50
PER CENT OF WATER OF MIXTURE IN WEIGHT OF CEMENT.

Experiment No. 9.

This was an experiment to determine the relation existing between the stiffness of cement mortar when first mixed and its subsequent strength. The stiffness depends on the proportion of water used in mixing, and varies somewhat with different cements. Natural American cements take up more water than Portland cements, and fine-ground more than coarse cements. Many series of tests bearing on this point were made. The results obtained from two of the more complete series are shown by the curves on Plate XXX. The cements used in these tests were a rather coarse English Portland and a fair Rosendale. Each of the points in the curves represents an average from about ten briquettes. The cements were tested neat, and the amounts of water used were different percentages, by weight, of the amounts of cement. The resulting stiffness of mortar is indicated on the curves. This varied from the consistency of fresh loam to a fluid grout. The time of settling is greatly retarded by the addition of water.

The curves show that from 20 to 25 per cent. of water gives the best results with Portland cement, and from 30 to 35 per cent. with Rosendale ; that the differences in strength due to the amount of water are considerable at first, but diminish greatly with age ; that the soft mortars, even when semifluid, like grout, attain considerable strength in time.

Experiment No. 10.

From the first it was observed that fine-ground cements were less strong when tested neat, and stronger when mixed with sand, than were coarse cements. A few examples of this are given below. In the first table a coarse English Portland cement is compared with a fine-ground French Portland. The per cent. of each retained by the fine No. 120 sieve is given, and the tensile strength, in pounds, per square inch at the end of seven days.

Table No. 8.

Kind of Cement.	Per Cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.				
		0	2	3	4	5
English Portland	37	319	125	89	59	43
French Portland	13	318	205	130	114	86

Such examples could be multiplied. German Portland cements were commonly finer ground than English, and, as a rule, were no stronger or less strong, tested neat, but were much stronger with liberal proportions of sand. In the following table two lots of the same brand of English Portland cement are compared. The coarse cement was the ordinary make of the manufacturers; the fine cement differed in no particular from the other except that it was ground more slowly and finer to meet the requirements of a special agreement. The age of the samples when broken was 28 days: —

TABLE NO. 9.

Kind of Cement.	Per Cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.		
		0	3	5
Ordinary Cement	35	403	105	68
Fine-ground Cement . . .	12	304	180	96

Different brands of Rosendale cement varied considerably in their fineness. Those of the best reputation would leave from 4 to 10 per cent. residuum in the No. 50 sieve; other brands would leave in the same sieve from 10 to 23 per cent. In the following table is compared the average tensile strength obtained from experiments with three of the finer-ground brands, and also with three other brands of good reputation, but more coarsely ground. The age of the specimens was one week: —

TABLE NO. 10.

Kind of Cement.	Per Cent. retained by No. 50 Sieve.	Parts of Sand to 1 part of Cement.		
		0	1.5	2
Fine Rosendale	6	92	41	25
Coarse Rosendale	17	98	29	16

The foregoing experiments show that it is impossible, by tests on the tensile strength of neat cements alone, to judge of their value in making mortars, for practical use; also, that fine-ground cements make stronger mortars than do coarser ones.

A number of series of tests were made of cements which had been sifted through sieves of different degrees of fineness, and had thereby had different percentages of coarse particles removed from them. The results from these experiments were quite uniform, and showed that, in proportion as its coarse particles were removed, a cement became more efficient for making mortars with sand. The following table gives the results obtained from one such series of tests made with an English Portland cement. In the experiment comparison is made between the strength of mortars made with the ordinary cement, unsifted, as it came from the barrel, and those made with the same cement after having been sifted through Nos. 50, 70, 100, and 120 sieves, which, respectively, eliminated more and more of the coarse particles. The per cent. of particles which would still be retained by the fine No. 100 sieve, after sifting through the coarser sieves, is given in the second column of the table. There is included in the table an extra coarse cement, which was made so by adding to unsifted cement a certain amount of the coarse particles taken from the sifted cements. The tensile strength is given in pounds per square inch.

Table No. 11.

Kind of Cement used in making Mortars.	Per Cent. of Particles retained by No. 120 Sieve.	One Week.				One Month.				Six Months.				One Year.			
		Parts of Sand to 1 part of Cement.															
		2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
Cement with coarse particles added	55	72	39	32	19	117	80	67	40	210	135	122	84	200	128	112	92
Ordinary Cement unsifted	33	129	92	58	43	197	143	109	88	311	236	183	136	288	247	168	165
Cement which passed No. 50 Sieve	28	159	97	67	47	210	158	125	102	324	246	190	146	328	249	214	170
Cement which passed No. 70 Sieve	18	163	117	82	65	239	168	151	112	338	256	225	173	342	295	230	193
Cement which passed No. 100 Sieve	8	177	123	84	73	255	185	156	122	257	288	239	182	382	307	257	215
Cement which passed No. 120 Sieve	0	198	154	95	86	271	200	161	132	379	320	238	196	386	316	262	218

In a similar series of tests with Rosendale cement mortars the increase in strength obtained by substituting fine for coarse particles in the cement was much less marked. The coarse particles were softer than those from Portland cement, and had, in themselves, some power of cohesion. As previous tests had shown that fine-ground Rosendale cements were stronger, with sand, than coarse-ground, it was assumed that the superiority was due not so much to the absence of palpably coarse particles, as to the fact that the bulk of the cement was more floury, and thus better adapted to coating and binding the particles of sand. Probably natural American cement is as much improved as is Portland cement by fine grinding; but in the case of the former there would not be the same relative advantage in bolting out the coarse particles after grinding.

The following series of tests may be of interest on account of the age of the specimens. The mortars were made with an English Portland cement, both unsifted as taken from the cask, and also after it had been sifted through the No. 120 sieve, by which process about 35 per cent. of coarse particles was eliminated: —

Table No. 12.

Kind of Cement.	Neat Cements.		Cement, 1; Sand, 2.		Cement, 1; Sand, 5.	
	2 Years.	4 Years.	2 Years.	4 Years.	2 Years.	4 Years.
Ordinary Cement, unsifted	603	387	339	493	182	202
Cement which passed No. 120 Sieve . .	374	211	478	580	250	284

This table also shows that fine cements do not give as high results, tested neat, as do cements containing coarse particles, even coarse particles of sand. It also shows (what is often noticed) that neat cements become brittle with age, and are apt to fly into pieces under comparatively light loads.

The series of tests which follows was made for the purpose of ascertaining what value, if any, for cementing purposes, was possessed by the hard, coarse particles of Portland cement. Mortars were made with an ordinary English Portland cement, and compared with similar mortars made with the same cement, after sifting through the No. 120 sieve, which retained 33 per cent. of coarse particles.

PLATE XXXI

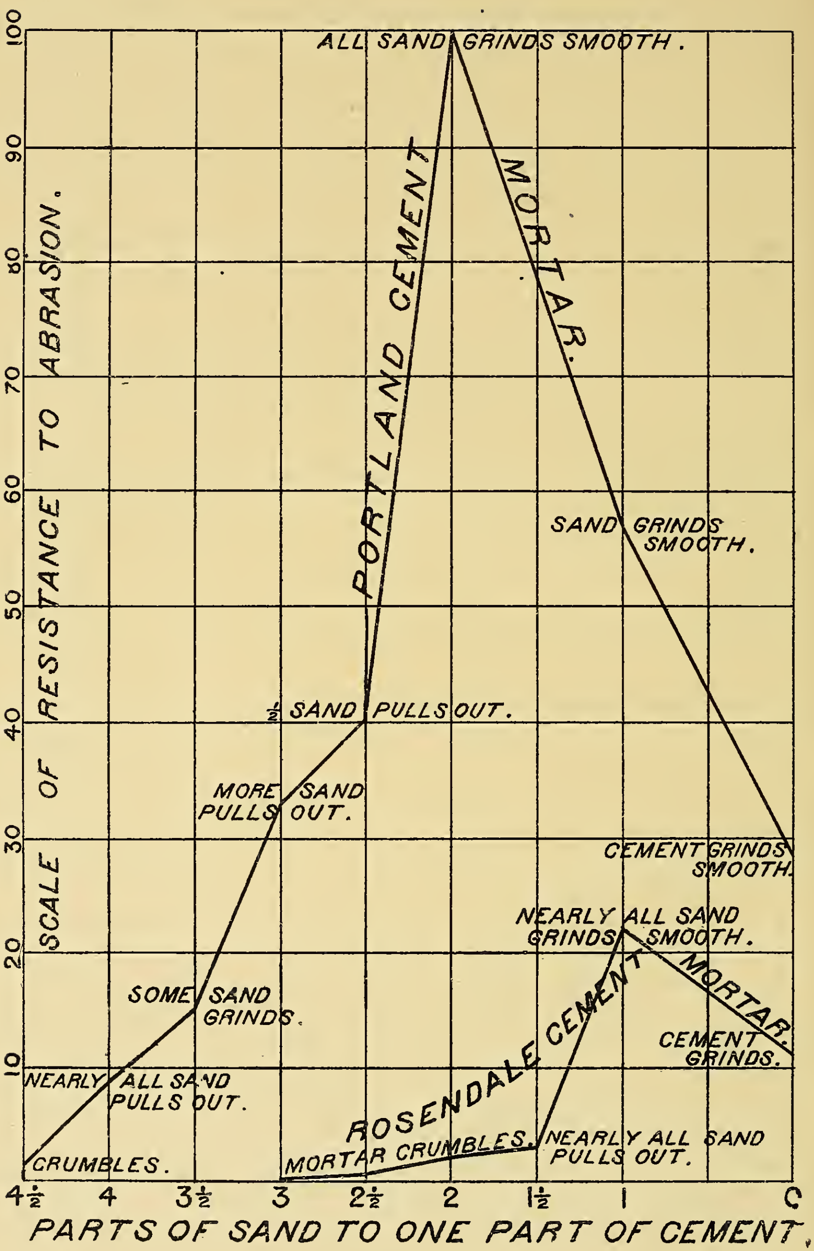

SCALE OF RESISTANCE TO ABRASION.
100
90
80
70
60
50
40
30
20
10
ALL SAND GRINDS SMOOTH.
PORTLAND CEMENT
MORTAR.
SAND GRINDS SMOOTH.
½ SAND PULLS OUT.
MORE SAND PULLS OUT.
CEMENT GRINDS SMOOTH.
NEARLY ALL SAND GRINDS SMOOTH.
SOME SAND GRINDS.
ROSENDALE CEMENT
MORTAR.
CEMENT GRINDS.
NEARLY ALL SAND PULLS OUT.
CRUMBLES.
MORTAR CRUMBLES.
NEARLY ALL SAND PULLS OUT.
4½
4
3½
3
2½
2
1½
1
0
PARTS OF SAND TO ONE PART OF CEMENT.

TABLE No. 13.

Kind of Cement.	One Week.			One Month.			Six Months.			One Year.		
	Parts of Sand to one part of Cement.											
	0	2	3	0	2	3	0	2	3	0	2	3
Ordinary Cement unsifted .	353	139	86	279	201	142	438	323	253	444	343	271
Cement which passed No. 120 Sieve	311	187	132	243	275	201	268	367	310	306	434	333

As usual, the coarse cement was stronger neat, and weaker with sand. Assuming that the 33 per cent. of coarse particles retained by the sieve had *no* value as cement, acting merely as so much sand, and assuming also that all which passed through the sieve was good cement, it follows that the ordinary unsifted cement with two parts of sand, made a mortar in which the proportion of real cement to sand was .76 to 2.33, or about 1 to 3.5. Hence the mortar made with fine cement and three parts of sand should be as strong, or a little stronger, than that made with the coarse cement and two parts of sand. It will be seen that the results in the table sustain the assumption very well.

If, then, the coarse particles are assumed to act merely as so much sand, it will not lessen the efficiency of the cement to remove its coarse particles, and to substitute actual sand in their place. This was done in making the following series of tests. One set of briquettes was made with ordinary cement, and another set with the same cement, from which 33 per cent. of coarse particles had been removed and replaced with fine sand.

TABLE No. 14.

Kind of Cement.	One Week.		One Month.		Six Months.		One Year.	
	Parts of Sand to one part of Cement.							
	2	3	2	3	2	3	2	3
Ordinary Cement, unsifted .	139	86	201	142	324	253	343	271
Cement with 33 per cent. coarse particles removed and fine sand substituted.	101	67	160	100	253	206	305	240

These briquettes refused to break in accordance with the theory, and the assumed hypothesis was not verified. It is evident that, for making mortar, the coarse particles of Portland cement are superior to ordinary sand, but much inferior to fine cement. In the mortars made with the cement in which the coarse particles had been replaced with fine sand, the real proportions of cement to sand were 1 to 3.5 and 1 to 5. It will be noticed that the tensile strength was not reduced in like proportion.

Experiment No. 11.

While building masonry laid in American cement mortar it is sometimes desirable to increase the strength of the mortar temporarily or in places. Rich Portland cement mortars are expensive, and those with large proportions of sand are too porous for many purposes. The desired strength can be gained by using, instead of the simple American cement, the same cement mixed with a percentage of strong Portland cement.

The following series of tests was designed to ascertain the comparative strength of mortars made with a Rosendale cement, an English Portland cement, and also a mixture composed of equal parts of each: —

Table No. 15.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Rosendale Cement, 1; Sand, 2 . .	26	60	125	180
Rosendale Cement, 0.5, Portland Cement, 0.5, } Sand, 2 .	79	138	268	273
Portland Cement, 1; Sand, 2 . . .	126	163	279	323

In the foregoing tests the mortar made with mixed cement had an unexpected strength, approximating to that of mortar made with pure Portland cement. In the following series of tests of mortars made with lime of Teil, a fine-ground French Portland cement, and the lime and cement mixed, the strength of the mortar made with the mixture is almost exactly a mean between those of the other two mortars, as also the cost of the mixed cement is a mean between the costs of the other two.

TABLE No. 16.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Lime of Teil, 1; Sand, 2	40	65	150	195
Lime of Teil, 0.5, Portland Cement, 0.5, } Sand, 2 .	100	135	255	290
Portland Cement, 1; Sand, 2 . .	170	265	350	365

The best Portland cements sometimes do not set within an hour, which precludes their use for wet-work. In such cases quick-setting cement should be added to them. Roman cements can be procured which will set in from one to five minutes. Mixtures of Roman and Portland cements were often used on the Main Drainage Works. Such mortars would set about as quickly as if made with Roman cement alone, and would acquire great subsequent strength, due to the Portland cement contained in them. This was proved by many experimental tests.

It is probable that mixtures of any good cements can be used without risk; but before adopting any novel combination it would be wise to test it experimentally.

EXPERIMENT No. 12.

Engineers are accustomed to require that only clean sand and water shall be used in making mortar. Occasionally these requirements cause delay and extra expense. This experiment was designed to ascertain how much injury would be caused by the use of sand containing moderate proportions of loam. In mixing the mortar for these briquettes, sand containing 10 per cent. of loam was used in the place of clean sand. Each figure in the table is an average (in pounds per square inch) of ten breakings.

TABLE No. 17.

ROSENDALE CEMENT, 1; SAND, 1.5; LOAM, .15.

One Week.	One Month.	Six Months.	One Year.
21	46	200	221

The tests do not give very decisive results. For one week and one month the breaking loads are not much more than one-half what would have been expected with clean sand. For six months and a year they are fully equal to ordinary mortar.

Experiment No. 13.

This experiment was similar to the foregoing one, except that clay, instead of loam, was added to the mortar. Clay, when dissolved or pulverized, consists of an almost impalpable powder, with particles fine enough to fill the interstitial spaces among the coarser particles of cement. By adding clay to cement mortar a much more dense, plastic, and water-tight paste is produced, which was occasionally found convenient for plastering surfaces or stopping leaky joints. Each figure in the Portland cement series of tests is an average from about fifteen briquettes; those in the Rosendale cement series are averages from ten briquettes.

Table No. 18.

ROSENDALE CEMENT.

	Cement, 2; Clay, 1.	Cement, 1; Clay, 1.	Cement, 1; Sand, 1.5.	Cement, 1; Sand, 1.5; Clay, 0.15.	Cement, 1; Sand, 1.5; Clay, 0.3.	Cement, 1; Sand, 1.5; Clay, 0.45.
1 week . .	32	23	50	52	34	33
1 month . .	108	52	123	116	101	100
6 months . .	303	206	217	248	247	236
1 year . . .	208	209	262	290	265	261

PORTLAND CEMENT.

	Cement, 2; Clay, 1.	Cement, 1; Clay, 1.	Cement, 1; Sand, 2.	Cement, 1; Sand, 2; Clay, 0.2.	Cement, 1; Sand, 2; Clay, 0.4.	Cement, 1; Sand, 2; Clay, 0.6.
1 week . .	185	192	150	197	185	145
1 month . .	263	271	186	253	245	203
6 months . .	348	322	320	361	368	317
1 year . . .	303	301	340	367	401	384

The tests seem to show that the presence of clay in moderate amounts does not weaken cement mortars.

It was feared that the presence of clay in mortars exposed to the weather might tend to make them absorb moisture and become disintegrated. To ascertain whether this would be so, sets of briquettes were made, one set of Portland cement and sand only, the other containing also different amounts of clay. They were allowed to harden in water for a week, and were then exposed on the roof of the office building for two and one-half years, when they were broken. All of the briquettes appeared to be in perfectly good condition, with sharp, hard edges. Their average tensile strengths in pounds per square inch are shown in the following table: —

TABLE NO. 19.

Portland Cement, 1;	Sand, 2			402
"	"	Clay,	0.5	262
"	"	"	1.0	256
"	"	"	1.5	182
"	"	"	2.0	178

The mortars with clay show a very fair degree of strength, and the tests confirm the belief that the presence of clay works little, if any, harm. Tests of mortars made with lime and clay also gave favorable results. Such mortars would stand up in water. The subject is worthy of further investigation.

EXPERIMENT NO. 14.

Occasionally, for stopping leaks through joints in the sewers, it was found convenient to use cement mixed with melted tallow. The tallow congealed at once and held the water while the joint was being calked. Briquettes made of melted tallow mixed with Portland cement and sand, equal parts, acquired in 1 week, a tensile strength of about 40 pounds to the inch. After a month, six months, and a year, they were little, if any, stronger. It was thought that possibly the ammonia in the sewage might gradually saponify and dissolve out the grease, leaving the mortar to harden by itself. Briquettes of cement and tallow were kept in water, to which a little ammonia was added from time to time. After a year or two the briquettes had swelled to about double their former size, but the cement had acquired no strength.

EXPERIMENT NO. 15.

Having occasion to build with concrete a large monolithic structure, in which a flat wall would be subjected to transverse stress, it was considered necessary to make experiments, to find the comparative resistance to such stress of concrete made with different cements and with different proportions of sand and stone.

The cements used in the tests were an English Portland and a Rosendale, both good of their respective kinds. Medium coarse pit sand was used, and screened pebbles about an inch or less in diameter. The beams were ten inches square and six feet or less long. They were made in plank moulds resting on the bottom of a gravel-pit about four feet deep. After the concrete had hardened sufficiently the moulds were removed, and the undisturbed beams buried in the pit and left for six months exposed to the weather. They were then dug out and broken, with the results given in the table. The total breaking loads are given, including one-half of the weights of the beams, which averaged about 150 pounds per cubic foot. The constant, c, is obtaindd for the formula: —

$w = \frac{d^2 \times b}{l} \times c$, in which

- w = centre breaking load in pounds.
- d = depth of beam in inches.
- b = breadth of beam in inches.
- l = distance between supports in feet.
- c = a constant.

Since c has an average value, and there were generally more beams of one length than the other, the value of c as given does not exactly correspond with either load in the table.

TABLE No. 20.

Proportion of Materials.			Average Centre Breaking Weight in Pounds.		Average Modulus of Rupture in Pounds.	Average Value of c in Pounds.
Cement.	Sand.	Stone.	Dist. between Supports. 2′ 4½″.	Dist. between Supports. 5′.		
Rosendale, 1 .	2	5	1,782	690	67	3.7
" 1 .	3	7	Beams broke	in handling.		
Portland, 1 . .	3	7	3,926	1,995	176	9.8
" 1 . .	4	9	3,648	. . . .	146	8.1
" 1 . .	6	11	2,822	1,190	112	6.2

The table shows that concrete has a rather low modulus, especially when made of Rosendale cement. When transverse stress is to be opposed it is very important to give ample time for the concrete to harden.

Experiment No. 16.

Many of the main drainage sewers were either built or lined with concrete, which was always smoothly plastered with a coat of mortar. It was important that this surface coat should be especially adapted to resist abrasion. This experiment was made to ascertain the best mixture for the purpose. Different mortars were formed into blocks $1\frac{1}{2}$ inches square, and, after hardening under water for 8 months, were ground down upon a grindstone. The blocks were pressed upon the stone with a fixed pressure of about 20 pounds. A counter was attached to the machine, and the number of revolutions required to grind off 0.1 inch of each block was noted. The cements used in the test blocks were a rather coarse English Portland and a fair Rosendale.

The curves (Plate XXXI.) show the results obtained. In making these curves the resistance to abrasion opposed by the Portland cement mortar in the proportion of one part cement and two parts sand is assumed to be 100, and the resistance of other mortars is compared with it. The effect of the grinding upon the test blocks is noted on the curves, and explains the somewhat striking results.

It appears that cements oppose the greatest resistance to abrasion when combined with the largest amount of sand which they can just bind so firmly that it will grind off and not be pulled out. A little less or a little more of sand may greatly lessen the resistance. For any given cement the proper amount of sand would, probably, have to be ascertained by experiment.

Experiment No. 17.

It is a prevalent belief among masons that cement, even when it contains no free lime, and does not check, expands considerably after setting. It is stated that brick fronts laid with cement mortar (especially of Portland cement) have been known to bulge, and even rise, owing to expansion in the mortar. Experiments were made to ascertain what truth there was in this belief. Several dozens of glass lamp-chimneys were filled with mortars made of various brands of American and Portland cements, both neat and with different admixtures of sand. The chimneys were immersed in water, and, without exception, began to crack within three days. New cracks appeared during the following ten days, after which time hardly a square inch of glass remained which did not show signs of fracture. This showed that the cement certainly expanded, though very slowly, and that the expansion continued for about two weeks. None of the cracks opened appreciably, however, so that the *amount* of expansion, which was evidently slight, could not thus be even approximately determined.

A number of 10-inch cubes were then made of similar mortars, with small copper tacks inserted in the centres of all the sides. Some of these cubes were kept in the air, and others immersed in water, and the sizes of all of them were measured frequently by callipers during six months. The increase in size did not in any case exceed .01 inch, and may have been less. This indicated that, while cement mortars do expand, the increase in bulk in any dimension does not exceed .001 part of that dimension, and is too slight to be of consequence. In the case of the walls before referred to, supposing them to have been 80 feet high, with five $\frac{1}{4}$-inch joints to each foot, the total height of mortar would have been 100 inches, and the extreme expansion of the whole could only have been .1 inch. It is probable that the apparent rise was merely a difference in elevation caused by settlements of partition or side walls laid with weaker and compressible mortar.

Experiment No. 18.

It having been reported that cement mortars in contact with wood had sometimes been found to be disintegrated, as if they might have been affected by the wood acids, this experiment was made to see if any such effect could be detected. About a dozen boxes were made, each formed of five different kinds of wood, viz., oak, hard-pine, white-pine, spruce, and ash. The boxes were filled with different cement mortars, and were some of them submerged in fresh and others in salt water. Briquettes were also made of cements mixed with different kinds of sawdust. At the end of a year no effect upon the cements could anywhere be detected.

Experiment No. 19.

Engineers are accustomed to insist on cement mortars being used before they have begun to set, and on their being undisturbed after that process has begun. With cements that set quickly workmen are tempted to retemper the mortar after it has begun to stiffen. Some experiments were made on mortars which were undisturbed after first setting, and others which were retempered from time to time. Unfortunately all of the conditions of these tests were not accurately recorded, and the results are not considered trustworthy. The following series of tests, which represent an extreme case not met with in actual practice, may be of interest.

A mortar, made of one part of Portland cement and two parts of sand, was allowed to harden for a week. It was then pulverized, re-tempered, and made into briquettes. These subsequently acquired the following tensile strength in pounds per square inch: —

1 week	7
1 month	13
6 months	49
2 years	93

Under the circumstances it is somewhat surprising that the mortar developed as much strength as it did. Good tests to elucidate this subject are much needed.

Experiment No. 20.

A brand of "Selenitic" cement was offered for use on the work, and was said to possess great merits. It was made by treating an ordinary American cement by a patented process. It was tested by comparing it with an untreated sample of the same cement of which it was made. The following are the results of the tests: —

Table No. 21.

Mixture.	Kind of Cement.	1 Day.	1 Week.	1 Month.	6 Months.	1 Year.
Neat . . .	Untreated .	124	135	140	164	186
Cement . .	Selenitic .	149	168	171	282	273
Cement, 1 .	Untreated .	. . .	122	176	296	316
Sand, 1, 5 .	Selenitic .	. . .	120	158	276	356
Cement, 1 .	Untreated .	. . .	92	154	259	305
Sand, 2 . .	Selenitic .	. . .	103	133	226	276
Cement, 1 .	Untreated .	. . .	38	87	158	168
Sand, 4 . .	Selenitic .	. . .	49	97	167	164

The breakings are somewhat irregular, but seem to show that this cement was made somewhat stronger by the selenitic process of treatment when tested neat, but was little, if at all, improved for use as a mortar; not enough, certainly, to compensate, for the higher cost.

APPENDIX B.

REVIEW OF ACTION OF THE CITY COUNCIL IN REGARD TO THE ORIGIN AND PROGRESS OF THE MAIN DRAINAGE WORKS.

THE defects of the sewerage system of Boston and the necessity for a radical change were brought to the attention of the City Council in various ways, for a number of years preceding the year 1875. The State Board of Health referred to the subject in their annual reports as seriously affecting the sanitary interests of
1873. the city, and requiring immediate attention. In 1873 the following order was passed (July 14) by the City Council: —

Ordered, That the Committee on Sewers be requested to examine into the present system of sewerage in this city, and report to the City Council whether any improvement of the present sewerage facilities is necessary for the protection of the public health.

In pursuance of this order the Committee on Sewers reported September 1, following (City Doc. 94); but, judging from their report, they did not consider that any improvement in the existing sewerage system was required, as they endeavor to show that it was sufficient and served its purpose as well as almost any other in existence. To quote from the report, the committee state that "Our system of drainage is as perfect, though not so complicated, as that of any other city. We are favored by location with generally good grades and outlets to deep water, and though we have no long lines composed of huge sewers with their many branches, with pumping-works and flushing apparatus, yet the removal of the sewage from the house to the ebbing tide in the harbor is rapid and complete; and *that* is a perfect system."

After comparing the system of Boston with that of other cities in the country, the committee conclude their report by stating that "Everything which appears necessary to the public health or convenience will be carried out by the Department as soon as it is possible

or expedient." The report is signed by Aldermen James **1873.**
Power, Alanson Bigelow, and Thomas Gaffield.

Notwithstanding the reassuring tone of the report of the Committee on Sewers, complaints continued, and the defects and dangers of the drainage system of our city were still commented upon in various ways. The Boston Board of Health, in their annual report, presented to the City Council in August, 1874 (City Doc. **1874.**
63), in discussing the subject, state: —

The whole system of sewerage is clearly wrong. Our beautiful city is almost encircled by the mouths of sewers discharging their contents into shoal water or upon flats, the sewer gases rendering the atmosphere for some distance about the wharves absolutely dangerous to breathe. About these wharves are large numbers of laborers, whose duties are always there; and within range of these gases are thousands of dwellings. Should not all the sewers be turned south-easterly, into deep water? Or would it be more feasible to construct a large marginal sewer, into which all others should discharge their contents, and this one carried away into deep water from a point nearest the bay? These are important questions, and deserve to be carefully considered, requiring, as it seems to us, the immediate investigation of experienced engineers.

There are large neighborhoods in the city entirely destitute of sewers, or any proper means of getting rid of their vault, sink, or cesspool drainage, and much sickness exists in these places in consequence.

There are also, in various parts of the city, low marsh lands, which are unhealthy; in the Charlestown District there are 200 acres; in Brighton, 400; in West Roxbury, 127. There are more than 200 acres of land east of Hampden Street, in Ward 13, that ought to be raised; a large portion of the territory east of Harrison Avenue, between Dedham and Northampton Streets, is too low. So is the Berlin-street territory, and it has caused us a great deal of trouble. The territory bounded by Swett, Hampden, Foundry, and Gerard Streets should be raised. And we respectfully submit that no marsh land should be allowed to be inhabited, nor a building be allowed to be placed on it, until proper and sufficient drainage is provided. We mean drainage independent of sewerage. If we stop to reflect how greatly health and comfort are affected by undrained land we shall easily see that such spots should not be inhabited. There are a great many vacant lots of land in the city without any drainage, and the city should neither cause nor allow water from the streets to flow upon these lots.

We are satisfied that all sewers should discharge their contents into deep water, and as far out into the harbor as possible, and in no instance should the mouth of a sewer be exposed, even at the lowest tide.

In December of the same year the Board of Health presented a special communication on the subject to the City Council (City Doc. 112), and as the communication, without doubt, occupies an important place in this review, affecting the initiatory steps taken by the City Council for improving the sewerage system, it is reprinted here entire: —

1874.

Office of the Board of Health,
Boston, Dec. 17, 1874.

To the Honorable City Council: —

Gentlemen, — Although in our annual report of 1873, and again in 1874, we called the attention of your honorable body to the great importance of a change in our system of sewerage, we deem it of such vital importance to the health and comfort of the city at large, but more especially to certain portions of it, that we venture again to urge the subject in a special communication.

There are several places in which the evil is already so great that we mention them in particular.

First. The old Roxbury Canal, crossing under Albany Street, near Chester Park.

Second. The Stony-brook Sewer, discharging upon the Back-bay flats.

Third. The Muddy-brook Sewer, between Brookline Avenue and Downer Street, in Ward 15.

Roxbury Canal, so called, leads in from the South Bay, is about 50 feet wide and 2,000 feet long, reaching nearly to Harrison Avenue. The tide flows in and out, but sluggishly. Into these three or four large sewers pour their contents, and when the tide recedes there is left but very shoal, filthy water, through which the foul gases from the putrid bottom can be seen bubbling into the atmosphere. At low tide a considerable portion of this filthy bottom is left bare, giving off the most sickening and even dangerous effluvia into a thickly populated neighborhood. In Northampton Street, Chester Park, Springfield Street, Harrison Avenue, Albany Street, and especially at the City Hospital, where there is a daily average of 230 patients who require pure air, the stench from the Roxbury Canal is often observed and exceedingly annoying.

The Stony-brook Sewer, which conveys the sewage of more than half of the former city of Roxbury, or now about 30,000 inhabitants, terminates at the west side of Parker Street, where, at low tide, this immense sewage is left to trickle over the muddy flats, about 100 acres in extent, to the Charles River beyond. Before this sewage has reached a point where it can diverge from the wharves of the city, it will have travelled more than one-half of the circumference of the city proper, catching at the bridges, wharves, and upon the flats in its course.

An order has recently been passed by the City Council to extend the channel of the Stony Brook, so as to prevent the discharge of the sewage upon the flats next Parker Street.

In addition to the Stony-brook Sewer there are eight others opening into Charles River above Cambridge Bridge, which, with their open mouths at low tide, discharging their gases into the atmosphere, and their contents into shoal water or upon flats, are doing a great share in making the atmosphere of that part of the city skirting the river and Back Bay at times absolutely unfit to breathe.

The Muddy-brook Sewer, coming from Brookline, is very large, opens under Brookline Avenue, near Tremont Street, and is then an open sewer in the immediate rear of dwelling-houses between Brookline Avenue and Downer Street for a distance of 600 feet, and then crosses the avenue again into the town of Brookline. The water in this brook gets very low in summer, leaving but little besides the sewage-matter to flow through it. The stench from this is very bad, and the people who live near it justly complain. This sewer ought to be covered at once, for a distance of about 600 feet, to prevent evil results which must inevitably come from its present condition. **1874.**

The places mentioned, although the worst, are not all to which we invite attention. The city proper, being nearly surrounded by tide-water and flats, is to the same extent literally fringed with the open mouths of sewers, discharging their gases into the atmosphere, and their other contents upon the shoals, which are left bare next the sea-wall and under the wharves by the receding tide.

The result is, that at low tide, and especially in summer, about the wharves and skirts of the city, where thousands of the laboring classes must work during the day, and many more will resort for a cool breeze in the evening, the air, instead of being pure and cool from the water, as it should be, is polluted and made dangerous by the foul breath of the sewers.

That our prevalent summer diseases are largely influenced by this poisoned atmosphere there can be no sort of doubt. The best remedy for the evil complained of may not be so apparent as the evil itself. We beg to suggest, however, that whatever disposition is ultimately made of the sewage, whether carried inland and utilized, or seaward and lost, it would not be discharged at all points in the circumference of our city. If it is to be discharged into the sea — and this for Boston seems the most practicable — there should be the least possible number of outlets, and those well out into the channel of the harbor. We believe the time has come when large main sewers, which can be relied on for the next century, to collect and convey the sewage of all others to a proper place for disposal, or to the sea, should be laid. We believe that the very best interests of the city, public economy, and the public health, would be well served by beginning this work with the least necessary delay.

The discharge of sewage into the Charles River and the South Bay is a constantly growing evil, which already annoys and discomforts many, and, if permitted to go on, must soon exert a very serious influence upon the health of the entire city. This danger can be averted by carrying the sewage of the city proper, of East Boston and Charlestown District, by one large main from each, fully into the channel of the harbor, where, in deep water and strong currents, the material will be so dissipated and acted upon by the salt-water as to become harmless and unobjectionable to the senses before it can be lodged about the city by flood tide. That of South Boston and of the Highland and Dorchester districts should be carried well into deep water in Dorchester Bay.

To carry out these suggestions would require surveying and advice of competent engineers, who would carefully consider and report not only the best course and plan for these mains, but what they would need to be, without alteration, for the next fifty or one hundred years.

There are many places within the limits of the city, especially in the newly annexed territory, where, although a supply of water has been furnished, there are no means of getting rid of it after it has done its service, and the result is a perfect saturation of the soil about the dwellings, etc., by the vast overflow of cesspools and vaults. Typhoid fever and other preventable diseases are frequent in these places, and we fear must continue to be until proper sewerage is instituted.

While it is to be regretted that water-pipes have anywhere preceded the laying of sewers, it is but fair to say that the supply of pure water from the pipes, in some of the sections referred to, had become a necessity, and the people would have suffered, but in a little different way, without it.

1874. In many instances the well-water gets vitiated in quality, or deficient in quantity, and the supply from the pipes becomes a great blessing.

We would respectfully recommend all possible hastening of the sewers, and a halting of the water-pipes in those sections where the two are not now associated.

THE BOARD OF HEALTH,
By A. W. BOARDMAN,
Chairman.

The communication was referred to the Committee on Sewers; but as the municipal year was just at its close the matter went over, without any definite action thereon, to the committee of the
1875. succeeding year. The committee of 1875, — Aldermen Thomas B. Harris, James Power, and Clinton Viles, — instigated by the communication coming to them as unfinished business from their predecessors, presented an order in the Board of Aldermen, Feb. 23, 1875, which was amended somewhat and adopted March 1, in the following form: —

Ordered, That His Honor the Mayor be hereby authorized to appoint a commission, to consist of two civil engineers and one competent person skilled in the subject of sanitary science, to report upon the present sewerage of the city; the discharge of sewers into Charles River, Stony Brook, South Bay, or Dorchester Bay; the necessity of any high-water basin on the site of the present full basin, for flushing purposes; the expediency of relieving the sewers at the South End by pumping; and to present a plan for the outlets and main lines of sewers for the future wants of the city; and report, if it is expedient, in connection with the proposed works, to provide for any water-basins or marginal drive-ways, as ornamental and sanitary features of the city; and also an approximate estimate of the expense of any place, or places, for a system of sewerage submitted by them; the expenses to be paid from the appropriation for sewers.

In pursuance of this order His Honor Mayor Samuel C. Cobb appointed E. S. Chesbrough, of Chicago; Moses Lane, of Milwaukee; and Charles F. Folsom, M.D., of Boston, to serve as members of the commission. Their report was submitted (City Doc. 3,
1876. of 1876), and in it they recommended the construction of two intercepting sewers, one for the north side of Charles River, and the other for the south side, discharging at Shirley Gut and Moon Island, respectively; the total estimated cost of the combined system being $6,551,064.

This report was referred, January 13, to a joint special committee, consisting of Aldermen Alvah A. Burrage, Solomon B. Stebbins, and Thomas J. Whidden, and Councilmen Eugene H. Sampson, J. Homer Pierce, Warren K. Blodgett, Marcellus Day, and Albert H.

Taylor. A remonstrance from George B. Emerson and others was received May 4, 1876 (City Doc. No. 59) against the adoption of the plan of the commissioners, and requesting that additional investigations be had upon the subject. Petitions in favor of the plan proposed were received, June 12, from Edward H. Clarke and others, members of the Suffolk District Medical Society, and Jesse L. Nason and others, citizens and property-holders in Boston, representing that a new system of sewerage was of paramount importance, and praying that action be taken at the earliest possible day to secure to the city the benefits of the same. **1876.**

The special committee presented a preliminary report, February 14, 1876, advising immediate application by the City Council to the General Court for authority to take land required for the construction and maintenance of the proposed new sewer, and the following orders, submitted by the committee, were passed, namely: —

Ordered, That His Honor the Mayor be requested to petition the General Court, at its present session, for the passage of an act authorizing the city of Boston to take such land as may be needed for the construction and maintenance of a main sewer, across or under tide-water, to that part of the town of Quincy known as Squantum, and from thence to Moon Island, in said town of Quincy; also for authority to take land for the purpose of establishing pumping-works and reservoirs in the city of Boston and said town of Quincy.

Ordered, That His Honor the Mayor be requested to petition the General Court, at its present session, for the passage of an act regulating the construction and maintenance of sewers by the combined action of adjoining municipalities.

Acting under authority of the orders, the Mayor made application in due form to the Legislature, and in compliance with his petition the desired authority was obtained in the following act: —

[Chapter 136.]

An Act to empower the City of Boston to lay and maintain a Main Sewer, discharging at Moon Island in Boston Harbor, and for other purposes.

Be it enacted, etc., as follows: —

Section 1. The city of Boston shall have authority, in addition to the powers now possessed by it, for the purpose of laying and maintaining a main sewer running south-easterly from direction of Charles River, to build and maintain wharves, pumping-works, and reservoirs for said sewer, on the main land at or near the mouth of Neponset River, thence to conduct said sewer, by means of a siphon or tunnel under the bottom of the harbor, at or near the mouth of said river, to that part of the town of Quincy called Squantum; thence along or across said Squantum and the flats adjacent thereto to Moon Island. Said city shall also have authority to build and maintain a reservoir or reser-

1876. voirs at Moon Island, and other works essential to a proper and convenient discharge of the contents of said sewer. In any construction over tide-water said city shall be subject to the direction of the harbor commissioners in the manner pointed out in chapter four hundred and thirty-two of the acts of the year one thousand eight hundred and sixty-nine.

SECT. 2. The city of Boston shall have authority to take such lands, buildings, wharves, and structures, as may be necessary to accomplish the objects of the preceding section; and all damages to private property, or for lands, buildings, wharves, or structures taken under this act, shall be ascertained as prescribed in chapter forty-three of the General Statutes, and paid by the city of Boston.

SECT. 3. The city of Boston and the town of Brookline may contract with each other for the use and support in common of the city sewer now constructed in Beacon Street in Boston, and leading into Charles River, and for the building by said town at its sole expense within the limits of said city of a sewer about nine hundred feet in length from the town line to connect the town drains with such city sewer, and for the support, at the joint and equal expense of each, of the outlet of the sewer and the carrying the same out farther into Charles River if necessary; they may also contract with each other for the building and support in common of a new covered channel for Muddy River, such new channel to run from Tremont Street along the line of division between said city and town, and to empty into the channel of Muddy River east of Aspinwall Avenue. If it shall be necessary to take land for the purpose of carrying out the provisions of this section, said city and said town, each within its own territory, may take such land as may be necessary, and persons aggrieved by such taking shall have their damages ascertained and paid, and all the proceedings shall be conducted in conformity to the laws applicable to the laying out town-ways in said town, and highways in said city.

Approved April 11, 1876.

Subsequently, June 12, 1876, the committee submitted their report (City Doc. No. 66) upon the subject-matter that had been referred to them.

In it they recommended the adoption of the commissioners' plan so far as it applied to the territory south of Charles River, stating that "Present necessities would be met by the construction of a main intercepting sewer from Tremont Street to Moon Island. . . . . The application of the system to the district north of Charles River will require the coöperation of adjoining municipalities, and, as the necessities are not so pressing in that locality, it may be deferred for the present."

The estimated cost of the main intercepting sewer recommended by the committee was $3,550,070. They also suggested that an immediate appropriation be made for preliminary surveys, and their suggestions were embodied in the following orders, which accompanied their report: —

Ordered, That the Auditor of Accounts be, and he hereby is, authorized to transfer from the Reserve Fund the sum of $40,000, to constitute a special appropriation for the purpose of making surveys and plans, and of procuring estimates for an improved system of sewerage for the city of Boston. **1876.**

Ordered, That a joint special committee, consisting of three members of the Board of Aldermen, with such as the Common Council may join, be appointed to take charge of the construction of a main intercepting sewer from Tremont Street to Moon Island, together with a main outfall sewer, and the necessary reservoir and pumping-works connected therewith, substantially according to the plan recommended by the Commissioners on the Sewerage of Boston, in City Document No. 3, 1876; and said committee shall have authority to employ such assistants as may be needed to enable the City Engineer to perform the preliminary work required to carry out said plan; the expense therefor to be charged to the special appropriation for that purpose.

Messrs. Blodgett and Taylor dissented from the recommendations of their associates on the committee. The report and orders were referred to the Committee on Finance.

The latter committee reported, July 3, recommending the passage of the following as a substitute for the foregoing orders: —

Ordered, That the Auditor of Accounts be, and he hereby is, authorized to transfer from the Reserve Fund the sum of $40,000, to constitute a special appropriation for the purpose of making surveys and plans, and of procuring estimates for an improved system of sewerage for the city of Boston, and that said appropriation be expended under the supervision and direction of the Joint Special Committee on Improved Sewerage.

This order provoked considerable discussion in the two branches of the City Council, upon the general subject of sewerage (See City Council Proceedings, 1876, pp. 406–409, 421–425, 436–439), but was finally adopted July 17, 1876, after being amended by inserting after the words "city of Boston," the words "on a line from Tremont Street to Moon Island, and also on a line from said street to deep water, east of Castle Island."

The City Engineer, under the committee's direction, assumed charge of the work contemplated in the order, and a few days later he appointed Mr. Eliot C. Clarke as principal assistant in immediate charge of the preliminary surveys, etc., and work was commenced thereon without delay.

Mayor Frederick O. Prince, in his inaugural address to the City Council of 1877, in referring to the subject of sewerage, said: — **1877.**

No subject at this time claims so large a share of your serious consideration as that of sewerage. The health, prosperity, every interest, in fact, of our people depend upon it.

1877. Do you expect Boston to maintain its present position among the other cities of the country? Do you wish her to increase in wealth, in commercial importance, in political influence, to be what we claim she is, the model metropolis? See to it, then, that she shall have pure, as well as free, air for the lungs of her people.

The importance of perfect sewerage and good drainage, cleanliness, and ventilation cannot be overstated.

The instructive letter of our fellow-citizen, the eminent Dr. Edward H. Clarke, upon this subject, addressed to the meeting of citizens held at Faneuil Hall in June last, assures us that "defective sewerage and imperfect drainage are sapping the health of the city."

In July last an appropriation of $40,000 was made to obtain accurate surveys, and procure true estimates of the cost of constructing works substantially upon the plan recommended by the commissioners. If this plan should be adopted it would, without doubt, give us a perfect system of sewerage for an indefinite time, however large our population may be. The cost of the works, or of any works which would secure the desired result, would be great; but I am sure that any additional taxation which they might require would be cheerfully submitted to by our tax-payers, because the adequate sewerage is a necessity; and whatever necessity demands it vindicates.

With the advent of the year 1877 and the new City Council a special committee[1] was appointed to resume charge of the work, deriving their authority from the following order, passed February 10, viz.: —

Ordered, That the Joint Special Committee on Improved Sewerage take charge of all matters relating to an improved system of sewerage, with authority to employ such assistants as may be needed to enable the City Engineer to perform the preliminary work now in progress; the expense therefor to be charged to the special appropriation for that purpose.

The work of making surveys and examinations was accordingly carried forward without interruption, and on July 9 the City Engineer reported to the committee that he was in a position to recommend a definite scheme, with estimates of its cost.[2] As this report is of special value, from its relation to the original scheme as adopted by the City Council, extracts are presented herewith covering the leading points.

The Engineer states: —

The investigations have now been carried so far that I am in position to recommend a definite scheme, and to give a preliminary estimate of its cost; and, understanding that it is the wish of your committee that a report should be made at once, I respectfully submit the following: —

A few days after the above order was approved Mr. Eliot C. Clarke was appointed principal assistant, to take charge of the surveys; and his report, which accompanies this, will show what work has been done in the office and

[1] See Appendix C for list of committees. [2] See Appendix, City Doc. No. 70, 1877.

in the field. There remains for me, therefore, little else than to state **1877.**
what conclusions have been arrived at, and to give the estimates of cost of the various schemes that have been considered.

All the schemes are alike in their main features, and correspond with that proposed and recommended by the commission appointed in 1875 to report upon the present sewerage of the city, and to present a plan for its improvement.

These features are: a system of intercepting sewers along the margin of the city, to receive the flow of the existing sewers; a main sewer, into which the former empty, and which, crossing the city, leads to a pumping-station; pumping-machinery to raise the sewage matter some thirty feet; an outfall sewer leading from the pumps to a reservoir situated at some favorable point for discharge; and a reservoir from which the sewage, accumulated during the latter part of ebb and the whole of flood tide, is to be let out into the harbor during the first two or three hours of the ebb.

In all the schemes it is assumed that at some future day a system of *high-level* intercepting sewers will be added, which will conduct to the outfall all sewage that can be delivered at the reservoir without pumping.

The Commissioners (Mr. E. S. Chesbrough, City Engineer of Chicago; Mr. Moses Lane, City Engineer of Milwaukee; and Dr. C. F. Folsom, Secretary of Massachusetts State Board of Health) state in their report (City Document No. 3, 1876) what the evils are in the existing sewerage system that require remedy, and give the reasons why a plan of the above description is recommended. While it will be needless to go over the whole ground here, it may be well to call attention to one or two of the more striking points.

In the existing system the sewage is discharged through some seventy different outlets along the shore lines of the city, and a number of these outlets may be said to be in the very heart of the city, — such as those which empty into the Roxbury Canal, South Bay, and Fort Point Channel.

As the borders of the sewered portions of Boston consists largely of broad strips of made land, filled to level planes only six or eight feet above mean high tide, the sewers are necessarily built with slight grades, and are so situated as to be tide-locked a large portion of the time. They discharge during the latter part of the ebb and the first part of the flood tides, so that the sewage, instead of being swept out into the harbor and there diffused, is carried inland, and such portion as will deposit in still-water is thrown down at the turn of the tide upon the broad areas of flats that exist within and around the city. This intermittent discharge produces other serious evils. During the time the sewage is accumulating in the sewers there is very little current in them, and, in consequence, deposits are formed which are not readily removed, and, when putrefaction begins, are the source of dangerous gases. Again, as the sewage accumulates and rises in the sewers the gases are compressed, and, since adequate ventilation is not provided, are liable to be forced through the house-drains into the houses.

The more important objects to be attained by an improved system of sewerage are, then, an uninterrupted removal of all sewage-matter from the vicinity of inhabited districts, and a discharge of this matter at such a point and under such conditions that it shall not be brought back to be thrown down on our shores.

The order of the City Council refers to two points of outlet only; but after its passage other points were urged as possessing merit, and the committee thought it would be best to give them some attention, since so doing did not seem to be at variance with the spirit of the order.

1877. Four points of discharge have therefore been considered, viz.: —

Spectacle Island.

Thompson's Island.

Castle Island.

Moon Island.

From these four points experiments with floats were made, to determine the direction and the force of the tidal currents, and to furnish a means of judging if the suspended matter of the sewage would be deposited where it would injure the ship channels or cause a nuisance.

Passing the Engineer's discussion of the first three points we come to the fourth as being specially favored by him, and quote the following: —

MOON ISLAND.

The float experiments show a good current setting by the head of Moon Island and passing out to the sound through Black Rock Channel.

The pole floats (which were usually about fourteen feet long and were used to obtain the mean velocity of the current) passed to the north, and the surface floats to the south, of Rainsford Island.

The northerly channel is the deeper one, and the one the strongest currents follow.

It would seem that for the first two or three hours of ebb tide the waters of Dorchester Bay discharge chiefly through the opening between Thompson's Island and Squantum Head, thus producing a strong current close in land on the north shore of Moon Island, at just the time it is proposed to discharge the sewage. This current, passing around Moon Head, meets another from Quincy Bay, and the two uniting pass out through Black Rock Channel, as before described. This union of the two currents is a very favorable condition, since the inner edge of the more northerly one becomes the thread of the combined currents; and, therefore, any matter discharged off the north point of the island will follow the deepest part of the channel and meet with the highest velocities; at least, whatever the cause, floats which were started comparatively near the shore at the point where it is proposed to discharge the sewage followed the thread of the current after leaving Moon Head.

A large number of experiments were made at this place, and for a detailed statement of the conclusions drawn from them I would refer you to Mr. Clarke's report. It will be sufficient to remark here that they clearly demonstrate that Moon Island is a favorable point for discharge.

Two plans, with this island for their outlet, have been studied; one known as the Old Harbor Point scheme, the other as the Commercial Point scheme. They differ chiefly in the location of the pumping-stations and of portions of the main and outfall sewers, these differences in location causing, however, a difference in some of the details, more particularly in the method of crossing the navigable waters lying between Boston and Quincy.

The main sewer in both schemes begins on Camden Street, near Huntington Avenue, and follows Camden and Northampton Streets to Albany Street, from whence it will take one of two courses, to be determined hereafter, one through Swett Street and the proposed East Chester Park extension, to a point about 700 feet east of the New York & New England Railroad; thence through private property to the corner of Boston and Mt. Verdon Streets; the other, through Hampden Street, Norfolk Avenue, Clapp Street, and private property to the same point; thence it follows Mt. Vernon Street to a point about 600 feet beyond Dorchester Avenue, there turning to the right and running to a point near Crescent Avenue and the Old Colony Railroad. At this place the lines in the two schemes separate. In the Old Harbor Point scheme, the sewer, passing under the Old Colony Railroad, traverses the long stretch of marsh land known as Cow Pasture to Old Harbor Point, where is located the pumping-station. **1877.**

A good foundation in clay is found for the sewer and pumping machinery at a convenient depth under the Cow-pasture marsh, and no piling will be required.

The outfall sewer leaves the point in a tunnel and passes under the navigable waters of Dorchester Bay, a distance of 7,920 feet, to Squantum Head. Here it rises to the surface, crosses Squantum Neck, and passes over the body of water between the Neck and Moon Island, to the reservoir on the island. A portion of the distance after leaving the Neck, where there is mud bottom, it is carried on a pile foundation, the remainder of the way on an embankment. For the whole of this distance beyond the Neck it is to be covered with a heavy embankment, heavily paved and riprapped where necessary.

The reservoirs will discharge through capacious outlet sewers carried well out into the tidal current.

The estimated cost of the Old Harbor Point scheme is as follows: —

Intercepting sewers	$706,000 00
Main sewer	565,000 00
Pumping-station, filth-hoist, and force-mains . . .	390,000 00
Sea-walls, filling, shaft-chamber, flushing-tank, etc. .	155,000 00
Outfall sewer, including tunnel	848,000 00
Reservoir and connections	421,000 00
Outlet sewer	28,000 00
Pier, box sewers, and connections	64,000 00
Dwellings for reservoir men, and other buildings . .	20,000 00
Extra, for relaying existing sewers, etc.	100,000 00
	$3,307,000 00
Add 10 per cent. for superintendence and contingencies .	330,700 00
	$3,637,700 00
Land damages	75,000 00
	$3,712,700 00

This estimate does not include the cost of land along East Chester Park extension, but does include the cost of filling 675 feet in length of that street to the full width and grade.

The more important advantages of this scheme are: —

First. A favorable point for the location of a reservoir and the discharge of sewage.

Moon Island is remote from any considerable population, present or prospective; therefore neither the presence of the reservoir nor the discharge of sewage there can have any effect upon the value of real estate.

1877. The sewage will enter favorable currents, which follow channels entirely outside inner harbor.

Second. The location of the pumping-station is also remote from any lands that would be liable to be depreciated by its presence, and is such that ample room can be had at moderate cost.

Third. The lines which the main sewer follows are such as to occasion comparatively little inconvenience during construction. After leaving Albany Street, if East Chester Park extension is followed, but one important line of travel will be interfered with, namely, Dorchester Avenue.

The chief objection to it is the siphon in the tunnel under Dorchester Bay. This feature is objectionable on account of difficulty of construction, and of the special appliances to keep it from silting up. A great deal of thought has been given to the latter point, and various methods for preventing deposit, and for flushing-out deposits, when they do occur, have been considered. The method finally adopted for purposes of the estimate is a large, covered flushing-tank at the west shaft, into which the sewage will be pumped, and afterwards let through the siphon with a velocity sufficient to prevent deposit, or to remove any that may exist. At the east end a sump is provided, into which heavy matter, if any should find entrance to the tunnel, will be swept thence to be dredged up through the east shaft. European experience in the use of siphons for sewerage purposes may show that so much in the way of precaution is unnecessary; if so the plans can be modified.

The Commercial Point scheme, having also its proposed outlet at Moon Island, is described by the Engineer; the estimated cost being $4,372,300.

Comparing the two schemes, *i.e.*, the Commercial Point and Old Harbor Point, he states in conclusion, that

The difficulties to be met in the construction of the Commercial Point scheme, taken in connection with the excess of cost and other matters of less importance, render it inferior to the Old Harbor Point scheme; I would therefore recommend this latter as the best of the three, all things considered.

The report of the Assistant Engineer, Mr. Eliot C. Clarke, in charge of the surveys, and also "A Report on the Geology of the District traversed by the Surveys for the Tunnel from Boston to Moon Island," prepared by Prof. N. S. Shaler, accompanied the Engineer's report. (See Appendix, City Doc. No. 70, 1877.)

Acting upon the recommendations made by the Engineer the committee presented their report to the City Council July 12, and, after reviewing the origin and progress of the work thus far, they state: —

At the beginning of the present year the undersigned were appointed to take charge of the work of making the preliminary examinations for an improved system of sewerage, and it has been performed under their direction until the present time. The results are clearly set forth in the reports of the City Engineer and the principal assistants in charge, which are hereto appended, together with a report from Professor N. S. Shaler, who was consulted with regard to the geological questions which arose during the progress of the survey. **1877.**

Your committee believe that it is unnecessary to present any argument to prove the necessity of adopting a comprehensive system of sewerage for this city. The ground has been fully covered by former reports upon the subject. In such matters great reliance must be placed upon the opinions of persons who have made sanitary science a study; and, if the mass of testimony which has been presented from time to time be reviewed, it will be seen that the evils arising from defective sewerage are discernible in this city to an alarming extent.

While it is not assumed that an improvement in the system of sewerage will secure to us complete immunity from disease, it is believed that it will remove a powerful agency for evil. Aside from questions of health, it is well known that great discomfort is occasioned to the residents of many parts of the city, who are compelled to inhale the odors occasioned by the present method of discharging our sewerage. It is believed that the necessity of the improvement will be admitted, whatever differences of opinion there may be as to the proper method of relief.

The plan for an improved system of sewerage which is now presented has the indorsement of the best engineering talent in the country. It is the result of a careful study of the different systems of sewerage now in practical operation, and an application of the best features of such systems to meet the present and future wants of Boston. It is unnecessary for your committee to attempt to explain the details of the proposed plan; for that they refer to the reports and plans of the engineers. It will be seen that the plan agrees in all its essential features with the one originally recommended by the Commissioners.

Your committee have made a careful study of the scheme, and are convinced that it presents the only practicable method of effectually removing the evils which are inseparable from our present system. It appears to be the only feasible method of securing the conditions demanded of a complete system of sewerage, viz.: the immediate and uninterrupted removal of sewage from the vicinity of our dwellings to a point from whence it will not return.

The report was signed by all the members except Councilman Blodgett, who dissented from the recommendations of the others.

The committee recommended the passage of the following orders: —

Ordered, That the City Treasurer be, and he hereby is, authorized to borrow, under the direction of the Committee on Finance, the sum of three million seven hundred and twelve thousand seven hundred dollars; the same to constitute a special appropriation for the construction of an improved system of sewerage.

Ordered, That the Joint Special Committee on Improved Sewerage be authorized to contract on behalf of the City of Boston for the construction of an improved system of sewerage, having its pumping-station located at Old Harbor Point and its outlet at Moon Head, with all the reservoirs, pumping-works, and other appliances essential to the proper operation of said system, substantially in accordance with the plans made by Joseph P. Davis, City Engineer, and as authorized by an Act of the Legislature entitled "An Act to empower the City

1877. of Boston to lay and maintain a main sewer discharging at Moon Island in Boston Harbor, and for other purposes," being Chapter 136 of the Acts of the year 1876; the expense thereof to be charged to the appropriation for Improved Sewerage.

The orders were referred to the Committee on Finance, and that committee reported July 19 recommending the negotiation of a loan to the amount of $3,712,000. Interesting discussions of the subject took place in the two branches while under consideration (see City Council Proceedings, 1877, pp. 544, 559–567, 569–577), and in August the orders were finally passed.

This action of the City Council marks another important stage in our review of the work, as the city was thereby fully committed to the task of improving the sewerage system, and a definite plan was adopted.

By an order passed October 8, the City Engineer was allowed four months' leave of absence, for the purpose of visiting Europe, and examining the sewerage systems in use there; and the sum of $5,000 was allowed from the appropriation to defray his expenses, and Assistant Engineer Henry M. Wightman was empowered to perform the Engineer's duties during his absence.

December 27 a memorial from the Boston Society of Architects was received, and referred to the committee, wherein it was represented that the proposed new sewerage system would cause serious injury to the foundations of buildings on the Back-Bay territory by reducing the grade of the ground-water in that section to a point below the heads of the piling on which the buildings stood. The memorial was accompanied by a communication from E. S. Chesbrough stating that the apprehended evils could be averted by making the proposed sewer water-tight, and thus avoiding drainage from the surrounding soil.

During this year rooms were procured at No. 74 Tremont Street for the Improved Sewerage Department, and land was also purchased at Old Harbor Point as a location for the proposed pumping-station in connection with the work. Considerable portions of the construction-work were let out by the committee to different contractors, and good progress was made before the year closed.

Mayor Henry L. Pierce, in his inaugural address to the **1878.** City Council in 1878, referred to the subject, and said: —

The intercepting sewerage system, for which an appropriation was made last summer, and on which work has already begun, originated in the conviction of our citizens that some better method was needed than already existed for the removal of the city's sewage. **1878.**

While it is not claimed that the completion of this work will furnish a perfect system of sewerage, since the ordinary drains and sewers are to some extent defective in construction and arrangement, yet it seems to be the first and most important step in that direction, affording, as it will, an outlet into which the existing sewers can at all times freely discharge, and without which it would be almost useless to attempt to improve them.

By an order passed January 16 the committee were appointed to take charge of the Improved System of Sewerage, and they were clothed with the same powers as were exercised by their predecessors.

The committee having assumed charge of the work, under the authority conferred upon them, very little action relating to the subject appeared on the part of the City Council for that year. Questions of expediency as to the best method of carrying the work forward, whether by contract or day-labor, were discussed, and an order was passed in April allowing the committee to exercise their own judgment in particular cases.

By an order passed March 8 the committee were authorized to expend the sum of $14,775, as their proportion of the cost of extending Hereford Street from Commonwealth Avenue to Boylston Street, owing to the fact that the intercepting sewer was to be built in that street.

Orders were passed to take land for purposes of constructing the new sewer as follows: —

Old Harbor Point, February 9.
Boston & Albany Railroad, June 21.
Boston & Providence Railroad, June 21.
Calf Pasture, July 16.
Clapp Street, September 27.
Hyde and Wendell Streets, December 13.

The committee were authorized to modify contracts entered into by them in behalf of the city, under the following order, passed August 31, namely: —

Ordered, That, whenever in the opinion of the Joint Special Committee on Improved Sewerage it may be for the interest of the city that any contract entered into by said committee should be modified or abrogated, the said committee be, and they are hereby, authorized to modify or abrogate such contract, and enter into new contracts as they may deem expedient.

1879. The committee were appointed, as usual, in 1879, and the same powers were conferred upon them as were exercised by their predecessors in regard to carrying the work forward, employing labor, and also in regard to making and modifying contracts.

An order was presented in the Common Council February 27 requesting the committee to commence work as soon as possible, and providing that all the work, except such as was under contract, be done by day-labor. This order was referred to the committee for their consideration, and April 24 two reports were received on the subject. (See City Doc. 58.) The majority were in favor of constructing the sewerage-work by day-labor, so far as it was found expedient to do so, in the belief that the work could be done as cheap, if not cheaper, by that method than by contract, and with more satisfactory results. They state in their report that, —

The contract system is left open to many grave objections. The competition is so great that contracts are taken at extremely low prices, and the contractor is forced, as a measure of self-protection, to cheapen his work in every possible way. In the matter of materials it requires constant watchfulness to prevent the use of such as are improper, and the city is put to the expense of employing inspectors, in order to prevent imposition.

But it is in regard to the employment of labor that the greatest grievance exists. No control can be exercised over contractors in this respect. They employ whomsoever they please and at any price they see fit. It makes no difference whether the laborer is a citizen of Boston or a non-resident, so long as he can be hired for the lowest possible sum. Hence the constant complaints that come to the city authorities of the employment of the men from other places upon what is regarded as city work, and the cutting down of the prices of labor with what is thought to be the connivance of the city.

Your committee submit that if the work were to be done by the city many of these difficulties would be removed. In the first place, the work of superintendence could be performed at no greater expense than is now incurred for the employment of inspectors of contract-work. The materials can be purchased by the city as low, if not lower, than by contractors. The employment of labor will be under the direct control of the City Council, who can see to it that none but citizens of Boston are employed.

They recommended the passage of the following order: —

Ordered, That the Joint Special Committee on Improved Sewerage be authorized to construct Section 4, Main Intercepting Sewer, by day-labor, and to purchase such materials and supplies, and to employ such agents, as may be necessary therefor; the expense to be charged to the appropriation for Improved Sewerage.

The minority of the committee, Messrs. Stebbins and Mowry, dissented from the views of their associates, and opposed the system recommended by them, as being the most expensive generally. In their report they claim, — **1879.**

That in the construction of any extensive public work the same can generally be effected at much less expense, as also more expeditiously, under the contract system than by the adoption of any other method, and it is claimed that experience has proved this proposition to be correct. Especially has this been the case in connection with the construction of the intercepting sewer, now being laid in connection with our System of Improved Sewerage, as the cost of constructing said sewer under the contract system has been less by from twenty-five to thirty per cent. than it would have been provided said construction had been accomplished by day-labor. We therefore claim that if said intercepting sewer can be constructed at less expense to the city by the adoption of the contract system (provided such construction is effected in a workmanlike and satisfactory manner), it would be an unpardonable breach of trust to recommend the adoption of a more expensive method of construction, unless certain contingencies or emergencies necessitated the adoption of the latter method.

The matter provoked a great deal of discussion in the two branches of the City Council, and the order accompanying the majority report was finally rejected, June 3, by the Board of Aldermen. A similar order, however, was in the meantime introduced in the Common Council covering work upon the main intercepting sewer, and, after being amended, was passed, June 4, in the following form, viz. : —

Ordered, That the Committee on Improved Sewerage be empowered to construct a portion of the main intercepting sewer by day-labor, if they shall deem it expedient and for the best interest of the city to do so; and that in case they decide to build any portion of said sewer by day-labor, said committee be instructed to allow the superintendent in charge thereof to employ men of his own selection, who shall be citizens of Boston, without interference or dictation from the committee.

A report was submitted by the committee May 29, in compliance with an order passed May 13, giving a statement in detail of the expenditures on account of the work to that time. (See City Doc. 69, 1879.)[1]

An order was introduced in the Common Council August 26 fixing the minimum price for laborers on the work at $1.50 per day, and, after being discussed at some length and amended, it was passed in

[1] A general statement of expenditures follows the review, see p. 190.

1879. the branch where it originated, but it was finally rejected by the Aldermen.

Under authority of an order passed March 24 the Mayor petitioned the General Court for authority, on the part of the city, "to conduct the main sewer in a nearly direct line from Old Harbor to Moon Island, instead of by way of Neponset River and Squantum," as provided in the Acts of 1876, Chap. 136. In compliance with the Mayor's petition the following Act was passed: —

[CHAPTER 230.]

AN ACT IN ADDITION TO "AN ACT TO EMPOWER THE CITY OF BOSTON TO LAY AND MAINTAIN A MAIN SEWER, DISCHARGING AT MOON ISLAND, IN BOSTON HARBOR, AND FOR OTHER PURPOSES."

Be it enacted, etc., as follows: —

SECTION 1. The city of Boston shall have authority, in addition to the powers now possessed by it, for the purpose of laying and maintaining a main sewer running south-easterly from the direction of Charles River, to build and maintain wharves, pumping-works, reservoirs, and other structures on the main land, at or near the shore of the Calf Pasture, so called, in Dorchester Bay; thence to conduct said sewer, by means of embankments and of a tunnel or siphon, not less than six thousand five hundred feet long, under the bottom of the harbor to the part of the town of Quincy called Squantum; thence along or across said Squantum, and the flats and waters adjacent thereto, to Moon Island; or said city may build the sewer or siphon under the bottom of the harbor, on a nearly direct line from said Calf Pasture, to Moon Island. Said city shall have authority to build and maintain a reservoir or reservoirs, a pumping-station, wharves, and dwelling-houses, and such other works as are essential to a proper and a convenient discharge of the sewage at Moon Island. Said city shall have further authority to connect Moon Island with Squantum by means of a bridge or embankment to be used as a road-way. In any construction over tide-water said city shall be subject to the direction of the harbor commissioners in the manner pointed out in chapter four hundred and thirty-two of the acts of the year eighteen hundred and sixty-nine.

SECT. 2. The city of Boston shall have authority to take such lands, buildings, wharves, and structures as may be necessary to accomplish the objects of the preceding section; and all damages to private property, and for lands, buildings, wharves, or structures taken under this act, shall be ascertained as prescribed in chapter forty-three of the General Statutes, and paid by the city of Boston.

SECT. 3. This act shall take effect upon its passage. [*Approved April 16, 1879.*]

Orders to take land for the purposes of the sewer were passed as follows: Old Colony Railroad Company, April 18; Squantum and Moon Island, September 19. (See Doc. 91, 1879.)

Mayor Prince, in his inaugural address to the City Council, in 1880, referred to the work in the following manner: — **1880.**

The work has been well and economically constructed.

In view of the apprehensions which have been from time to time expressed touching the efficiency of this sewer in accomplishing its objects, it must be gratifying for you and your constituents to know that the able and experienced civil engineer, who is charged with this important work reports that after due consideration of the objections occasionally urged against the system, "Nothing has yet arisen to cause a doubt that the plan proposed is the proper solution of the sewerage problem at Boston and will afford the required relief."

The committee was appointed at the beginning of the year, and by an order passed February 20 were given the same powers as their predecessors, and the work progressed under their direction with but very little interference on the part of the City Council.

An order was passed February 20 allowing the sum of $3,000 to Hoblitzel & Co., from the amount retained by the city on their contract for building Section 5, main intercepting sewer.

The following order was passed May 5: —

Ordered, That the Committee on Improved Sewerage, acting under the advice of the City Solicitor, be authorized to purchase of Howard A. Carson and George H. Norman the right to use, in such departments of the city as may be necessary, the excavating machinery patented by said Carson; the expense, not exceeding $2,500, to be charged to the appropriation for Improved Sewerage.

An order was passed November 13 to take certain land in Quincy for sewer purposes. (See City Doc. 128.)

By an order passed December 29 the committee were authorized to alter or modify the existing contract with R. A. Malone for building the Dorchester-Bay tunnel to such extent as they might deem expedient.

Mayor Prince made reference to the work in his inaugural address in 1881, and said: — **1881.**

No unforeseen difficulties in the construction have been encountered, and there is every reason to expect the successful accomplishment of this part of the sewer scheme.

All the work has been well done, and it is gratifying to know that it has cost less than the present prices for labor and materials.

The Engineer does not doubt that this system of sewers will "ultimately accomplish all that has been claimed for it."

1881. The usual order for the appointment of the committee was passed January 3, and the committee were subsequently authorized to resume the work by an order passed January 28.

The matters coming before the City Council this year were chiefly in regard to modifications of contracts entered into in behalf of the city by the Committee on Improved Sewerage. The contracts modified by the City Council's consent were that of R. A. Malone, for building the Dorchester-Bay tunnel, and the contract with William C. Poland & Son, for building Section 3, outfall sewer, and Moon-island reservoir.

The committee were directed to report on these matters, and also in regard to the work under H. A. Carson's superintendence, and the following reports were accordingly submitted October 31. (See Doc. 135.)

DORCHESTER-BAY TUNNEL.

The Committee on Improved Sewerage, who were directed to report what progress has been made in the construction of the Dorchester-Bay tunnel, and whether the contractor for building said tunnel surrendered his original contract, and was given a new contract for completing the work, without bonds being required for the performance of the same, beg leave to report as follows: —

The three tunnel shafts, with their surrounding bulkheads and iron cylinders, are completed, with the exception of some brick lining. Of the total length of tunnel, amounting to 7,004 lineal feet, 5,329 feet are excavated, and the excavation of the remainder is at present progressing at the rate of about 200 feet per month.

Mr. Malone, the contractor for building the tunnel, in a communication to your committee, dated June 16, 1881, abandoned his contract, alleging his inability to complete it for the prices therein stipulated. Pending the action of the committee, to prevent damage to the work already accomplished, Mr. Malone continued to prosecute it. By the terms of the contract, as construed by the Corporation Counsel, two courses were open to the committee, — either to finish the work by day-labor, or to enter into a new contract for its completion, either with Mr. Malone or other parties. Mr. Malone offered to complete the work for prices about one-half greater than those of his previous contract. Considering the fact that Mr. Malone had the requisite plant on hand, and had acquired valuable experience concerning the character and best methods of conducting the work, and also that the bad reputation which the tunnel would have if abandoned, would probably deter other bidders from making reasonable offers, it was thought for the best interests of the city to allow Mr. Malone to continue to carry it on, — especially as his prices seemed reasonable to the committee and the Engineer, and were not in excess of figures of cost derived from the force-account kept by the city.

A new contract was therefore made with Mr. Malone for completing the tunnel. This contract was not accompanied by a bond — Mr. Malone not being in a position to furnish one. It should be understood, however, that **1881.** the bond upon the original contract has been in no way vitiated or impaired, the sureties having agreed that their liability should not be affected by these proceedings; and the amount of this bond, together with the reserve held back under the first contract, is still applicable to making good the loss incurred by the city through the abandonment of the original contract.

For the Committee,

LUCIUS SLADE,
Chairman.

THE POLAND CONTRACT.

The Committee on Improved Sewerage, who were directed to report what progress has been made in the construction of the works at Moon Island, under the contract with William C. Poland & Son, and also whether said contractors have surrendered their contract, beg leave to report as follows: —

The following tabulated statement will show the approximate total quantities of different classes of work required by Mr. Poland's contract, and the amounts now done as per Engineer's estimate, dated October 21, 1881: —

Class of Work.	Total Amount.	Amount Done.
Earth-work . . .	369,100 cubic yds.	201,827 cubic yds.
Masonry	59,520 " "	4,461 " "
Ballast	23,000 " "	10,865 " "
Riprap	55,000 tons.	15,470 tons.
Lumber	336 M.	170 M.
Drain-pipe	2,000 feet.	0 feet.
Brick gate-houses . .	2.	0.

By the terms of the contract the masonry of the reservoir, and the easterly two thousand feet of sewer, should be completed November 15, 1881. About one-twentieth part of the masonry is in place, and no part of the sewer is yet built. A large part of the cut-stone, for the reservoir and its adjuncts, is on the ground. The reservoir proper is about one-half excavated. The total value of the contract, as estimated from the contractor's bid, is $620,943.50. The value of work now done, according to the Engineer's approximate estimate of October 21, 1881, is $133,268.19.

The contract has not been surrendered; but the work is not now, nor has it been for some time past, progressing in a satisfactory manner. In view, however, of the fact that the Dorchester-Bay tunnel could not be completed in the time originally intended, your committee have not until now thought it necessary to take vigorous measures to forward the completion of the Poland contract. Arrangements are now in progress which, it is intended, shall result in an energetic prosecution of the work in the future.

For the Committee,

LUCIUS SLADE,
Chairman.

1881. THE CARSON CONTRACT.

The Committee on Improved Sewerage, who were directed to report what part of the work under their charge is being constructed by day-labor, in different sections of the city, under the superintendence of H. A. Carson, beg leave to report that Mr. Carson is superintending the construction of two sections of sewer, both in Albany Street. One is an extension of the south-side intercepting sewer in Albany Street, from its present terminus at Dover Street, through Albany and Lehigh Streets to Federal Street; the other is a sewer which takes the drainage of the Hampden and Northampton Street districts, and conveys it to the intercepting sewer.

For the Committee,

LUCIUS SLADE,

Chairman.

An order was introduced in the Board of Aldermen at their meeting April 11 (see City Council Proceedings, p. 214) requesting the Committee on Improved Sewerage "to submit in print a full and explicit account of all the circumstances attending the negotiations for pumping-engines, particularly with reference to the rejection of the engines made by Mr. George H. Corliss, and alleged to have been built under the implied contract with said committee." This order, after considerable discussion, was rejected by the Aldermen, but was afterwards reconsidered and passed. (See Proceedings, pp. 295, 316, 322.) The report of the committee not appearing, a second order calling for the report was presented at the meeting of the Aldermen October 10, and passed, but was indefinitely postponed in the Common Council November 10; and the same action was taken by the Council regarding orders adopted by the Aldermen for the appointment of a special committee to prosecute the investigation called for in the previous order. (See Proceedings, pp. 662, 663, 724, and 681, 690.)

An order was introduced at the Aldermen's meeting November 7 proposing the appointment of a commission, consisting of three persons, who, in conjunction with the Superintendent of Sewers and the City Engineer, should constitute "a board to be known as Sewer Commissioners, who shall take charge of all matters pertaining to the Sewer Department of the city, including the construction of the improved system of sewerage." (See Proceedings, p. 722.) This order was referred to the Special Committee on Commissions and Boards, who reported, November 28, in favor of the establishment of a Board of Commissioners, consisting of three persons, one to be appointed

by the Mayor and one to be elected by the City Council **1881.**
from each of the two branches, "said Board to have charge of all matters connected with the construction of the improved system of sewerage." But the municipal year being then so near its close the whole subject went over by reference to the next City Council.

The committee were appointed in 1882 and resumed work **1882.**
under authority conferred upon them by the usual orders.

An order was passed March 25 requesting the Board of Health "to consider and report whether the proposed discharge of sewage into Dorchester Bay will be prejudicial to the health or comfort of the inhabitants of South Boston." In pursuance of this order the Board of Health submitted their report upon the subject April 27. After referring to the surroundings of Old Harbor Point, the proposed point of discharge of sewage into the Dorchester Bay, and the various attendant circumstances that should be taken into consideration in discussing the question, the Board state that —

There will, in this case, be some deposit of sewage sludge about the outfall of the sewer and for a short distance from it; and, in time, it will undoubtedly be the cause of a local nuisance. But that this sewage will make its way across the channel and find lodgment on South Boston flats, or that the result of collection at the sewer outfall, in two or three years, will be sufficient to reach and harm or discomfort the inhabitants of South Boston, is improbable. If, on the other hand, discharge is made into the channel at the end of the pier, for two or three years, and only on the ebbing of the tide, there is no reason to expect any effect, local or diffused, which will be prejudicial to the health or comfort of the inhabitants of any section of the city or adjoining territory. On the contrary, we have every reason to say that the immediate use of this intercepting sewer is not only necessary to relieve the wretched unsanitary condition of other parts of the city, but that its use will materially improve the sanitary condition of South Boston itself. (See Proceedings, 1882, p. 222.)

The report was referred to the Committee on Improved Sewerage, with instructions to give a public hearing on the subject. Opposition was immediately developed to the proposed scheme of discharging the sewage into Dorchester Bay. A remonstrance from the Boston Asylum and Farm School at Thompson's Island was received May 1, and referred to the committee.

While the matter was under consideration by the committee, some of the citizens who were opposed to the scheme applied to the Legislature for relief, and procured the passage of the following act forbidding the discharge of sewage into Dorchester Bay : —

1882. [CHAPTER 256.]

AN ACT FOR THE PRESERVATION OF BOSTON HARBOR, AND OF THE PUBLIC HEALTH IN THE CITY OF BOSTON.

Be it enacted, etc., as follows : —

SECTION 1. No part of the contents of the main sewer, now or hereafter to be constructed, running south-easterly from the direction of Charles River in the city of Boston, shall be discharged at or near the shore of the Calf Pasture, so called, in Dorchester Bay, or at any place in Boston Harbor or vicinity except at Moon Island. The Supreme Judicial Court, or any justice thereof, upon the petition of not less than ten taxable inhabitants of the city of Boston, may restrain by injunction, or otherwise, any violation of the provisions of this act.

SECT. 2. This act shall take effect upon its passage. [*Approved May 26, 1885.*]

By the passage of this Act the action of the committee was anticipated, and they were relieved from further consideration of the subject.

At the meeting of the Aldermen April 17 the committee made a request for an additional appropriation of $1,500,000. A statement from the City Engineer accompanied the committee's request, and as it describes the condition of the work at that period, and sets forth in detail the various causes that had operated to occasion the necessity for an additional appropriation, it is herewith presented : —

IN BOARD OF ALDERMEN, April 17, 1882.

The Joint Special Committee on Improved Sewerage respectfully represent that an additional appropriation will be needed to complete the work under their charge.

The following is a summary of the state of the appropriation at the present time : —

APPROPRIATIONS.

Preliminary surveys	$40,000 00
Construction	3,713,000 00
	$3,753,000 00

EXPENDITURES.

Preliminary surveys	$25,214 22	
Construction	2,553,902 37	
Amounts carried forward,	$2,579,116 59	$3,753,000 00

1882.

Amounts brought forward,	$2,579,116 59	$3,753,000 00
Less stock on hand	23,012 12	
		2,556,104 47
Balance		$1,196,895 53
Amount called for by existing contracts		812,982 53
Balance on hand		$283,913 00

The estimated amount required to complete the work, in addition to what is now under contract, is . . .	$1,613,134 20
Less balance on hand	283,913 00
Deficit	$1,329,221 20

The following is a schedule of expenditures to March 1, 1882, inclusive: —

Intercepting sewers	$552,850 53
Main sewer	590,529 56
Pumping-station	581,854 16
Sea-walls, Old Harbor pier, etc.	143,216 87
Dorchester-Bay tunnel	333,408 87
Section 3, outfall sewer and reservoir	122,263 35
Connecting with old sewers . . . . . , .	22,047 77
Land damages	68,848 28
Superintendence and contingencies	138,882 98
Gross expenditures	$2,553,902 37
Less stock on hand	23,012 12
Net expenditures	$2,530,890 25

There will also be required for settlement of land damages and unsettled claims, connecting sewers at North End, running pumping-engines for temporary discharge of sewage into Dorchester Bay, and other items of expense not directly connected with the work of construction, a sum sufficient, in the opinion of the committee, to call for an additional appropriation of $1,500,000.

The accompanying communication from the City Engineer states at length the reasons for the increased cost of the work above the original estimates. It will be seen to be chiefly due to the rise in materials and labor, changes in plans of construction, rendered necessary to make the system conform to the best practice of modern sanitary engineering, and the expense of overcoming unforeseen difficulties in the work of construction. Although there is an apparent balance of $283,913, yet the greater part of this amount is required to complete

1882. work now in progress, and the committee do not feel authorized to enter upon the new work necessary to utilize that already completed or commenced until further provision has been made therefor by the City Council.

Respectfully submitted,

LUCIUS SLADE,
WILLIAM WOOLLEY,
CHARLES H. HERSEY,
MALCOLM S. GREENOUGH,
THOMAS J. DENNEY,
FRANK F. FARWELL,
NATHAN G. SMITH,
PRENTISS CUMMINGS.

APPENDIX.

Office of City Engineer, City Hall,
Boston, April 14, 1882.

To the Joint Special Committee on Improved Sewerage :—

Gentlemen, — As I am now able to estimate with approximate accuracy the final cost of the new sewerage system, I herewith submit for your consideration a statement of the present condition of the improved sewerage appropriation, the amount already expended, balance remaining, estimated expenditure in the future, and the further appropriation which will be necessary to complete the system as proposed.

By an order, approved June 17, 1876, there was appropriated the sum of $40,000 for a preliminary survey, to determine the practicability and approximate cost of a system of intercepting sewers for Boston. There was spent for this survey $25,214.22, leaving a balance unexpended of $14,785.78. By an order approved August 9, 1877, there was appropriated for the construction of an improved system of sewerage the sum of $3,713,000. The City Auditor, in his accounts, united the two appropriations under one head, entitled "Improved Sewerage," making the total appropriation on that account $3,753,000, As, however, the balance in cash to be transferred from the appropriation for a preliminary survey was only $14,785.78, the net appropriation available for Improved Sewerage construction was $3,727,785.78

March 1, 1882, there had been expended, chargeable to Improved Sewerage, the sum of $2,530,890.25, leaving a balance of $1,196,895.53. At the same time there existed contracts calling for payments in the sum of $912,982.53. This sum deducted from the balance of appropriation remaining leaves a second balance of $283,913, which is the amount available for construction not covered by existing contracts.

The estimated cost of such construction, necessary to complete the system, is $1,613,134.20. Deducting from this sum the available balance of $283,913, there is left $1,329,221.20 to be provided for otherwise than from the present appropriation.

That the committee may understand why the work has cost so much more than was at first estimated I present herewith a comparison of the estimate of July, 1877, with the present estimate, showing the increased expenditure for each item, and also offer some explanation of the reasons for such increase: — **1882.**

Comparison of Estimates of July, 1877, and March, 1882.

Items.	Estimates July, 1887.	Estimates March, 1882.	Increase.
Intercepting sewers	$706,000 00	$801,250 53	$95,250 53
Main sewers	565,000 00	595,389 47	30,389 47
Pumping-station, filth-hoist and force-mains .	390,000 00	999,857 25	609,857 25
Sea-walls, filling, shaft-chamber, flush-tank, etc.	155,000 00	360,681 93	205,681 93
Outfall sewer, including tunnel	848,000 00	1,130,415 97	282,415 97
Reservoir and connection	431,000 00	505,045 72	74,045 72
Outlet sewers, pier, box sewers, etc.	92,000 00	100,000 00	8,000 00
Dwellings at Moon Island	20,000 00	20,000 00	. . . .
Connecting existing sewers	100,000 00	120,000 00	20,000 00
	$3,307,000 00	$4,632,640 87	$1,325,640 87
Superintendence and contingencies	330,700 00	368,529 95	37,829 95
	$3,637,700 00	$5,001,170 82	$1,363,470 82
Land damages	75,000 00	78,843 28	3,848 28
Total	$3,712,700 00	$5,080,019 10	$1,367,319 10
Deduct stock on hand	. . . .	23,012 12	23,012 12
Estimated total cost and increase over estimate of July, 1877	. . . .	$5,057,000 98	$1,344,306 98
Deduct excess of net appropriation over estimates of July, 1887	. . . .	. . . .	15,085 78
Estimated deficit in appropriation	. . . .	. . . .	$1,329,221 20

Intercepting Sewers.

The increase in this item amounts to about 13½ per cent., and is wholly due to the increase in cost of labor and materials. The cost of a sewer depends almost entirely upon the prices paid for common labor and for bricks and cement. At

1882. the time the original estimate was made these prices were low, and there seemed no reason to anticipate an early advance. In fact, however, the whole work of construction has been carried on during a rising market, and on that account the contractors, almost without exception, have lost money. One-half in number of those having sewer contracts have been unable to fulfil their contracts, and several have gone into bankruptcy. On p. 6 is given a table of the principal items of cost entering into sewer-building, comparing the prices paid during the first years of construction with present prices: —

Item.	Former Price.	Present Price.	Increase per cent.
Labor, per day	$1 25	$1 75	.40
Bricks, per M.	7 26	11 00	.52
Cement, per bbl.	90	1 35	.50
Lumber, per M.	13 10	15 90	.21

Main Sewer.

The increase in this item amounts to but 5 per cent., and is more than covered by extra work not contemplated by the original estimate. As stated when the first estimate was made, it was intended to cover the cost of filling 675 feet of East Chester Park extension to its full width and grade. In fact, 1,700 feet in length of this street was so filled, and in addition the extension of Mt. Vernon Street across the Calf Pasture was graded for a length of 4,100 feet. The actual cost of sewer-construction was below the first estimate. This was due to the fact that the contracts for this work were among the earliest let, and nearly the whole sewer was completed before the extreme rise in prices. The contractors for three sections of main sewer were unable to complete their contracts, and one went into bankruptcy.

Pumping-Station, Etc.

Nearly one-half of the increase in cost of the whole system occurs in this item, and is due, in part, to the higher rates paid for labor and materials, but chiefly to the fact that the original estimate for this portion of the work was much too small. The principal items of expense at this point are as follows: —

2 pumping-engines	$215,000 00
2 " "	90,000 00
4 boilers	38,800 00
Force-mains	17,142 29
Foundations, wells, and filth-hoist	314,300 00
Buildings (Architect's estimate)	175,000 00
Chimney	6,250 00
Gates, and other machinery	35,000 00
Total	$894,492 29

In addition to the above are the salt-water conduit, the connection-chamber, and many other minor appurtenances. It would have been impossible to procure these necessary items for any approximation to the $390,000 provided by the first estimate. **1882.**

The work at this point has been done by day's labor under a superintendent appointed by the committee. Work done by the day is usually more expensive than contract-work; but it is also, usually, more sure, safe, and thorough. It may be doubted whether excavations of such magnitude, depth, and difficulty could have been made by contract without a single accident or mishap, or whether such thorough workmanship could have been obtained except by the method employed.

Sea-Walls, Flushing-Tank, Etc.

The increase in this item is very large, and is due to a radical change of plan adopted shortly after the first estimate was made. That estimate contemplated a tunnel-shaft on or near the main land. It was decided, however, in order that the tunnel might be wholly in rock, and also that the sewage, before entering it, might deposit any heavy matters held in suspension, to build the shaft 1,200 feet or more from the shore. At this point it was practicable to reach bed-rock. To convey the sewage to the shaft it was necessary to build elevated sewers, supported by a pier extending from the shore out to and around the shaft. The increase in this item represents very nearly the cost of this pier.

Outfall Sewer, Including Tunnel.

The work covered by this item was originally let for a sum within the first estimate; but the rise in prices obliged the contractors to abandon their contracts, and the work had to be relet for prices much greater than the previous ones.

Reservoir.

This work also was let for a sum within the original estimates, and has been relet at greatly advanced prices. The cost of the reservoir proper has been somewhat lessened by leaving off its roof, which was at first thought necessary.

On the remaining items the increase is slight, and is due to the general causes mentioned before. In the original estimate the item "Superintendence and contingencies" was made equal to 10 per cent. of the estimated cost of the work. For the work already done the amounts chargeable to this account are less than 6 per cent. of the expenditure. Should a similar rate be maintained there will be a gain in this item instead of a loss, but for a conservative estimate it has been assumed to be 10 per cent. on future work.

It is believed that the present estimate is ample to complete the system as proposed.

This estimate is based on the present rate of wages and price of materials. Should, therefore, any considerable advance in these occur, the expenditure for work not already contracted for will be correspondingly increased. This estimate does not include the cost of running the pumping-engines longer than will be necessary to thoroughly test them, nor does it include any extraordinary contingencies, such as expensive lawsuits, heavy payments for land damages, etc.

Respectfully submitted,

HENRY M. WIGHTMAN,
City Engineer.

1882. The matter was referred to the Committee on Finance, who reported favorably thereon in a report presented to the Board of Aldermen April 24. They recommended that the required amount of $1,500,000 be raised by loan, and the orders for the purpose, accompanying their report, were adopted May 13.

An order was passed September 19 authorizing a modification of the contract with N. F. Palmer & Co., for furnishing pumping-engines at Old Harbor Point.

The following order was passed November 17, but the committee failed to present any report in response thereto: —

Ordered, That the Committee on Improved Sewerage be requested to consider and report upou the expediency and cost of constructing a temporary wooden conduit, or otherwise connecting the Dorchester-Bay tunnel with Squantum Point, for the discharge of sewage in that locality, until the reservoir at Moon Island is completed; also, if expedient, to report the time required to construct and put in operation such temporary conduit or connection.

1883. In 1883 the work of the Improved Sewerage was referred to by Mayor Palmer, in his inaugural address, as follaws: —

The city is to be congratulated on the approaching completion of the New and Improved System of Sewerage. Speaking generally, it may be said that the whole system will be sufficiently advanced during the coming year to be made available for removing the most noticeable causes of nuisance in our present sewerage system. There will then remain to be built extensions of the intercepting sewers, to take the sewage from the north end of the city proper and the easterly portions of South Boston. The work thus far has cost somewhat more than was at first estimated, owing to the greatly enhanced prices of labor and materials since the preliminary estimates were made.

The total expenditures chargeable to this account, including the draft for January, 1883, is $3,388,045.89.

The committee were appointed at the commencement of the year 1883, and resumed work under authority of the orders passed by the City Council in the customary form.

A petition was received in the Board of Aldermen March 26 from Charles Linehan for relief under his contract for building Section 4, and claiming compensation for extra work. The petition was referred to the committee.

An order was passed June 30 to cancel the bond of R. A.

Malone, the contractor for building the Dorchester-Bay tunnel, upon his releasing all claims against the city on account of his contract. **1883.**

Also an order to pay C. W. Parker & Co. the sum of $25,000, from the amount retained on their contract for building Section 3, outfall sewer, and Moon-island reservoir; and, by an order passed December 15, a further allowance of $30,000 was made to said Parker & Co.

The following order was introduced in the Common Council March 8, and, after provoking considerable discussion, was passed March 14: —

Ordered, That in the employment of laborers by the Committee on Improved Sewerage there shall be no discrimination made against any residents of Boston.

No other matters of importance were acted upon by the City Council this year.

At the meeting of the Board of Aldermen December 31 Alderman Lucius Slade, the chairman of the committee, addressed the Board on the subject of the practical completion of the works and their going into operation the following day. He gave the following history of the work: —

Mr. Chairman, — To-morrow, the first day of January, 1884, the improved system of sewerage will go into operation, and, as I have been connected with the work, as a member of the committee, ever since the construction was commenced, I may be permitted to make a statement in regard to this great undertaking. In the first place let me say that the committee felt that it was desirable to put the system into operation at the earliest possible moment. And, therefore, although much remains to be done before the original plan will be completed, they decided to start the works at this time.

This scheme of improving the sewerage of the city was the outgrowth of a feeling of general dissatisfaction with the practice of discharging sewage into the docks and upon the flats surrounding our water-front, thereby creating a great and constantly increasing nuisance, which threatened soon to become intolerable, and also from the fact that it had become the conviction of scientific men that the practice of retaining refuse-matter in tide-locked sewers, from which noxious gases were generated that penetrated into our houses, was rapidly increasing the death-rate of the city, this increase being due to the prevalence of what are known as "filth diseases," which are directly traceable to emanations from defective sewers.

The first step toward the improved system was taken in 1873, when the Committee on Sewers were requested to examine the existing system and report what measures were necessary for the public health. The committee reported

1883. that everything which appeared to them necessary to the public health and convenience would be carried out by the Sewer Department as soon as it was possible and expedient.

Here the matter rested until 1875, when the Mayor was authorized to appoint a commission to present a plan for an improved system of sewerage, and Messrs. E. S. Chesbrough, Moses Lane, and Dr. C. F. Folsom were appointed commissioners. Messrs. Chesbrough and Lane were engineers, eminent in the profession, and Dr. Folsom was a scientific expert on the subject of sanitary matters, being recognized as one of the highest authorities on that subject. In 1876 the commissioners made their report. They pointed out the evils which existed in consequence of the way in which our sewers had been built, without a definite comprehensive system. They set forth the necessity of carrying the sewage away from the city before it had an opportunity to become dangerous to health by putrefaction. They showed that there were three ways in which we failed to accomplish this. First, the refuse did not always pass from the house-drains into the sewers, because the latter may be filled at high tide; the sewage may even be forced up the drains into the houses. Secondly, the sewers are not emptied promptly, because the tide or the tide-gates prevent it. In such case, the sewage being stagnant, a precipitate falls to the bottom of the sewer, and the slow and gradual emptying of the sewer as the tide falls does not produce scour enough to remove it. This deposit remains with little change, in some places, for many months. Third, when the sewage once reaches the outlets of the sewers it is again delayed there, to decompose and contaminate the air. They enunciated, as the cardinal principle of good sewerage, that the sewage should start from the houses and go in a continuous current, without stopping until it reaches its destination, either in deep water or upon the land.

To accomplish this result, after an exhaustive consideration of the subject, the commissioners recommended the present intercepting system, or, as it is better known, the improved system of sewerage. The opinions of these eminent gentlemen, expressed after a thorough study of the situation, attracted universal attention, and called for prompt action on the part of the City Council. Their report was referred to a Joint Special Committee, who in due time reported the orders necessary to carry the recommendations into effect.

Application was made to the General Court for the required legislation, and an act was passed authorizing the city to lay and maintain a main sewer discharging into Boston Harbor. An appropriation of $40,000 was made for the purpose of making preliminary surveys and preparing plans, etc., and an engineering force was immediately organized to make the surveys. In 1877 the City Engineer reported the result of the surveys. He indorsed the recommendation of the commissioners in regard to locating the works at Old Harbor Point and Moon Island.

The committee reported to the City Council in favor of constructing the works in accordance with the recommendations of the Engineer, and a loan of $3,713,000 was authorized. The committee soon after advertised for proposals for constructing certain portions of the work, and the first contracts were awarded on October 9, 1877.

In order to combine the results of the best engineering practice of this country and Europe the City Engineer was granted leave of absence, for the purpose of visiting Europe and studying the different foreign systems. This visit led to radical changes in some portions of the plans, all of which tended greatly to increase the efficiency of the works; and it is believed that the system now about to go into operation is the most perfect of its kind in existence. 1883.

A statement of the difficulties encountered and overcome in the construction of this great work would occupy too much of your time. It is sufficient to say that in the course of the work problems were presented which were new to engineering science, and which required the greatest talent and skill to solve successfully. That this was done is ample proof of the ability of those who had charge of the work. Let me briefly, and without going into technicalities, endeavor to give a description of the system which is now about to go into operation, and which is designed to carry out the recommendation of the commissioners, as expressed in the report I have already alluded to, — the immediate removal of sewage from the vicinity of our habitations.

The Improved System of Sewerage may be divided into four principal parts: —

1. The main and intercepting sewers, which convey the sewage to the pumping-station.
2. The pumping-station, where the sewage is raised.
3. The outfall sewer, by which the sewage is conveyed from the pumping-station to Moon Island.
4. The reservoir at Moon Island, in which the sewage is to be stored, and from which it is emptied during the early ebb tide.

The intercepting sewers follow the marginal streets of the city as far as practicable, and, intercepting the existing street sewers near their outlets, convey the sewage to the main sewer, which extends from the junction of Camden Street and Huntington Avenue to the pumping-station. The existing street sewers are joined to the intercepting sewers by small branches provided with gates to regulate the flow. The old outlets of existing sewers are, for the most part, kept open for use as storm overflows, those below tide level being provided with gates to prevent the tide from flowing in. The intercepting sewers are provided with flushing-gates for cleansing purposes, and with manholes and ventilating shafts at frequent intervals. Regulating-gates are also placed at their junction with the main sewer, to control the flow of sewage.

The main and intercepting sewers are about 15 miles in length. The sewage flowing into the intercepting sewers from the street sewers is conveyed in a continuous stream to the pumping-station at Old Harbor Point. At the pumping-station the sewage when it leaves the main sewer first passes through the filth-hoist, where all floating objects which would be liable to injure the pumps are intercepted. It then passes into the pump-wells, and from them is raised by the pumping-engines to a height of about 40 feet, and discharged through iron pipes into the connection-chamber, which forms the beginning of the tank sewer. The tank sewer is the commencement of the outfall sewer. It receives and conducts the sewage to the west shaft of the Dorchester-Bay tunnel. Here the sewage descends the west shaft a distance of about 160 feet, and pursues its course under Dorchester Bay until it reaches Squantum, where it rises to about its former level into another section of the outfall sewer. This tunnel was practically the key to the whole scheme. Here is where the greatest

1883. difficulties met with in the course of the work were encountered and successfully overcome, in spite of the prophecies of those doubters who believed that the construction of such a work was impossible.

These difficulties will never be fully appreciated except by those who watched the progress of the work from day to day, as I, in the capacity of chairman of the committee, was compelled to do. It may well be imagined that the drifting of a tunnel for a distance of about one mile and a quarter through solid rock, at a depth of 150 feet below the surface of Dorchester Bay, was a work which demanded indomitable energy and perseverance to carry it to a successful conclusion. When it leaves the tunnel the sewage passes through another section of the outfall sewer which conducts it to Moon Island.

On account of the difficulty of getting a suitable foundation this part of the sewer is not yet completed, so for the present the sewage will be conveyed to Moon Island in a temporary wooden flume constructed for the purpose. On arriving at Moon Island the sewage reaches the Reservoir Division. During the three hours of ebb tide it flows continuously through the outfall and discharge sewers into the tidal currents, which convey it beyond the limits of the harbor. If received at any other time it is stored in a massive masonry reservoir, covering 4½ acres of ground, and having a capacity of 25,000,000 gallons, where it is retained until the ebb tide, and then, together with sewage flowing in the outfall sewer, is discharged into the channel.

Next to the water-works, the system of sewerage which we put into operation to-morrow is the most important public work ever undertaken in this city, both as regards its magnitude and the purpose it is intended to accomplish. It is the only work of the kind on this continent, and if it succeed, as I believe it will, in removing the evils from which we have so long suffered, it cannot fail to prove a great benefit to the community. I am also glad to be able to say that no additional appropriation will be required to complete the work.

I have watched the progress of the work from day to day, and can testify to the faithful manner in which it has been done, and I also wish to express my appreciation and admiration of the talent and courage displayed by Mr. J. P. Davis, our former City Engineer, and his successor, Mr. H. M. Wightman, in overcoming all difficulties and carrying the work forward to a successful termination. Nor should I forget to bear witness to the ability and faithfulness of Mr. E. C. Clarke, the principal Assistant Engineer, and Messrs. S. H. Tarbell and H. A. Carson, the Superintendents, who have contributed so much to the satisfactory performance of the work. I can conceive of no more valuable or useful New-Year's gift that could be made to the public than this great work, a work which cannot fail to be a great blessing to the community.

1884. Mayor Martin referred to the Improved Sewerage Works, in his inaugural address before the City Council of 1884, as follows: —

The main drainage work, or improved system of sewerage, which has been in process of construction for several years, went into successful operation on the first instant. A full description of this important work having been lately given to the public it is unnecessary for me to enter into details here. The practical working of the system will be observed with great interest, and if it meet the expectations of its projectors, and relieve the city from the great evil of defective sewerage, the work will be a monument to the ability of those who designed and those who constructed it. **1884.**

The usual order was passed at the beginning of the year for the appointment of the committee, and authorizing them to resume the work.

An order was passed March 8 providing "that the expenses incurred by the committee in maintaining and operating the works under their charge be paid from the appropriation for Improved Sewerage."

Also, on March 8, an order was passed to allow the payment of a further advance of $10,000 to C. W. Parker & Co., in addition to the amount previously allowed them from the sum reserved on their contract for building Section 3, outfall sewer, and Moon-island reservoir.

The following order was introduced in the Common Council, September 11, and also in the Board of Aldermen September 28, namely: —

Ordered, That the Committee on Improved Sewerage be authorized to purchase a parcel of land in Calf Pasture, near the pumping-station, at Old Harbor Point, containing 45,709 square feet, as shown on a plan thereof in the office of the City Engineer, at the rate of five cents per square foot; the expense to be charged to the appropriation for Improved Sewerage.

The order was passed by the Aldermen November 10. Upon reaching the Common Council it was pretty carefully considered, and recommitted December 11 to the Committee on Improved Sewerage to ascertain and report whether the land in question could be taken by right of eminent domain. The committee reported December 18, and presented an opinion of the Corporation Counsel to the effect that the city had no authority to take the land for the purposes proposed. The order then went over by assignment to the last meeting of the Common Council, January 1, 1885, and a motion made at that meeting to take it up for consideration was lost.

An order was introduced in the Common Council June 12, 1884, by the committee authorizing them to purchase of Paul Butler and Henry W. Hunt the tract of land known as Squantum Head for the sum of $47,000. The committee were divided, however, regarding

1884. the expediency of making the purchase, and the order, after being pretty thoroughly discussed, was finally rejected June 19.

A communication was received from Henry Guild, by the Board of Aldermen, September 29, calling attention to an alleged nuisance, by reason of the very offensive odor from the sewage at Moon Island and Squantum. The communication was referred to the Committee on Improved Sewerage, and they submitted a report on the subject, October 13, stating that the odor complained of undoubtedly came from a small cove adjacent to the mouth of the discharge sewer, and extending to Moon Island; that the sewage-matter was carried into this cove by the water currents, and when the flats were exposed at low tide the offensive odor arose. They recommended as a remedy for the evil complained of that a dike be built across the entrance to the cove, at an estimated cost of $25,000. There being no provision in the Improved Sewerage appropriation for the extraordinary expenditure of such an amount, the report was referred to the Committee on Finance to provide the required sum; but that committee failed to report upon the subject.

An order was passed October 25 to pay to the Builders' Iron Foundry of Providence, R.I., an instalment of $3,300 from the amount reserved on their contract for furnishing machinery for the east shaft. An order was passed December 29 requesting the Mayor "to petition the General Court for authority to take from time to time such additional lands as the City Council may deem necessary for the purposes of extending and carrying out the system of improved sewerage," and also December 29 an order authorizing the committee to arrange for a visit of the City Council to the works, Tuesday, the 30th of December. Other matters presented to the City Council were simply claims of laborers and others.

President John H. Lee, of the Common Council of 1884, in his valedictory address to that body, thus refers to the Improved Sewerage works: —

The new intercepting sewer system was put in operation January 1, 1884, and has so continued during the year. Certain of the higher level sewers of the system, which were not built when the works were started, have been completed the past season. The permanent buildings at the pumping-station, and much other work at that place and at Moon Island, have also been finished during the same time. With the exception of the erection of the east shaft pumping-machinery, removal of old buildings, finishing of roadways and grounds, and some other minor details, the whole work may be said to be substantially completed. **1884.**

The year's operation of the system has demonstrated its efficiency in relieving the docks and bays from the nuisances formerly caused by the discharge of sewage into them, and in preventing the damming up by the tide of the city sewers, by which, during the greater part of the day, they were converted into stagnant cesspools. The system, although not designed to prevent wet cellars in the low sections of the city, has, nevertheless, relieved to a great extent the districts which formerly suffered the most from this cause.

Careful examinations made from time to time, during the year, have shown no evidence of deposits in the channels of the harbor through which the sewage discharged at Moon Island is conveyed to the sea by the tidal currents, nor is there any evidence of its fouling the shores of the islands or main lands in its passage.

The tunnel under Dorchester Bay, which it was thought might be impaired in its efficiency by deposits of sludge, is apparently free from such accumulations, or, if they exist, they do not furnish any appreciable obstacle to the flow of the sewage through it.

It would not, however, be safe to run this important section of the system without provisions for its periodical examination; and for this purpose the pumping-machinery for emptying it, which is to be erected at the east shaft, has been purchased, and is in readiness for setting up as soon as the rights to take the land necessary for the purpose can be procured.

Notwithstanding the complicated nature of the machinery and constructions connected with this new system of works, every portion of them has worked, from the start, on January 1, in the most efficient manner. No accident has occurred of any importance, nor any of any kind which has delayed or prevented the working of the system for a day. Of course this is largely due to the careful and intelligent management of the works, for which the Engineer's Department is responsible, under the direction of the Joint Special Committee on Improved Sewerage.

Mayor Hugh O'Brien referred to the subject in his inaugural address to the City Council, January 4, as follows: — **1885.**

The Improved System of Sewerage, or, as it should be more properly called, the Main Drainage System or Works, which has been in process of construction since October, 1887, is practically completed. Although certain portions of the works were unfinished at the commencement of the year it was decided to put in operation the completed portions on January 1, 1884. The pumps were, therefore, started for continuous duty on that date, and have run without interruption since. The results of the year's operations have been very satisfactory. The sewage of the city has been removed from places where it formerly created nuisances, and has all been discharged into the outer harbor at Moon Island. The water in the bays and docks around the city has again become pure, as evidenced by its being frequented by fish, which for years have been unable to live in it on account of the sewage contamination. The offensive odors formerly

1885. prevalent over the city during the summer were not noticed during the past season. In many portions of the city the cellars have been relieved from the periodical flooding caused by the surcharging of the sewers during storms and by the leakage into them of the tide-water; and, although the system was not built as a remedy for this evil, it furnishes a means by which it can be remedied in the future. Although the operation of the new system has been satisfactory, even more so than could have been anticipated, in view of the magnitude of the works, the complication of the machinery for operating them, and the difficulties inherent in every new work, yet the benefit to be derived from it is not so complete as it should be. The old system — if such a combination of sewers, many of which are badly designed and defectively constructed, can be called a system — is in such a condition that the sewage, before it reaches the intercepting sewers of the new system, is full of noxious gases. These gases are given off by the sewage in its passage to the intercepter and during its flow through it, and find their way into the houses and streets, carrying with them the germs of disease.

No remedy short of entire reconstruction of the defective sewers will prove effective. Some of them discharge at points too low to be intercepted, or even to empty at ordinary low tide; some of them have too slight a gradient to prevent deposits; and some of them have settled in such a manner as to make pockets into which the sludge settles and decomposes. That a system of sewerage shall be so constructed as to convey the contaminated fluids emptied into it to the point of discharge before decomposition has rendered them dangerous is an axiom of sanitary engineering.

In the Main Drainage Works the city has the basis for the best system of sewerage that modern science has yet been able to devise for similarly situated communities, and it should complete the work by adapting the old system to the new, so as to form one harmonious whole. To effect this a complete survey of the old sewers should be made, and, after a thorough study of the subject, plans should be devised for remedying the defects mentioned. The reconstruction of the defective portions of the system must necessarily be gradual. In the meantime the question arises, "Under whose direction should this work be undertaken, and in whose charge shall the new work be placed?" It seems proper that the new system should remain as at present, under the immediate supervision of the Engineer's Department, as its successful operation depends upon intelligent engineering care, which can best be given by those who have constructed it. It would also appear that the Engineer's Department is the proper department, under the city ordinances, to make the surveys and plans for adapting the old system to the new, and to have charge of such constructions as may be required. Admitting these views of the subjects, why should the sewerage system of the city be under two independent heads? It is not to be expected that they will work in harmony, and by their inharmonious working the city is subjected to unnecessary expense in the construction of sewers which may have to be rebuilt to conform to a proper system.

Under whatever Board, or commission, or committee, the sewerage system may be put, the entire work should be in the immediate charge of the Engineer's Department, as it was previous to 1869; and that department should be held responsible for all constructions connected with it. It should also be remembered that the new Main Drainage Works contemplate, and were designed and built for, a high-level sewer, which should intercept the sewage of the **1885.** high portions of Dorchester, Roxbury, etc., and convey it to Squantum, where a connection-chamber has been built, and beyond which point the system is large enough for both the low-level and high-level sewage, except as to reservoir capacity, which is to be made larger. In order that the sewerage system of these high-level districts should be properly designed and executed, this provision in the new Main Drainage Works should be borne in mind, and, that a great deal of unnecessary expense in this direction may be avoided, a careful survey and study of the whole of these districts should be made, and any sewers built should be so constructed as to be, ultimately, the most economical for connection with the high-level sewers of the Main Drainage Works.

The special committee was appointed, as usual, to take charge of the work, and by an order passed February 12 they were authorized to operate the Main Drainage Works[1] during the year.

The portion of the Mayor's message above quoted was referred, on recommendation of the Committee on Mayor's Address, to a special committee, consisting of Aldermen Allen and Mullane, and Councilmen Brown, Denney, and Keliher, to consider and report upon the expediency of consolidating the Improved Sewerage and Sewer departments. Their report was presented to the Aldermen at the meeting June 8, and in it they state that —

They have given the subject careful consideration, and have listened to the views of the officials and committees in charge of the two departments. The

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[1] Henry M. Wightman, the City Engineer, died April 3, at 8.30 P.M. He had held the position since 1880, being elected to fill the vacancy in the office occasioned by the resignation of Joseph P. Davis. Prior to 1880 Mr. Wightman occupied the position of Assistant Engineer for a number of years, and had served the city in humbler positions, connected with the Engineer's Department, since his boyhood. He was closely identified with the Main Drainage Works, and the most difficult and important portions of the work were carried forward under his direction. He was a man of marked ability, and thoroughly devoted to his duties, and by his death the city sustained the loss of a valuable and efficient public official.

The following resolutions of respect were unanimously adopted by the City Council, namely: —

Resolved, That the City Council of Boston has learned with sorrow and regret of the death of Henry M. Wightman, City Engineer.

Resolved, That the City Council hereby expresses its appreciation of the long-continued and valuable services rendered by Mr. Wightman to his native city. His ability and fidelity have been conspicuous throughout his official career, and his public service has been characterized by the strictest integrity. The important engineering works which he has successfully completed will endure as public memorials of his professional skill, while the recollection of the sterling and admirable traits of character which he possessed in such an eminent degree will be cherished in the memories of all who have been connected with him in the public service.

Resolved, That the City Clerk be instructed to transmit a copy of these resolutions to the family of the deceased.

(*See* Proceedings, pp. 243, 259.)

William Jackson was elected City Engineer, to fill the vacancy occasioned by Mr. Wightman's death.

1885. general sentiment, as expressed by the gentlemen who appeared before the committee, was in favor of consolidating the two departments, although they did not state exactly the time or the manner in which the consolidation should be effected. Your committee, on their own part, concur substantially in the opinion voiced by the representatives of the two departments, and they would accordingly report that, in their opinion, the consolidation should take place at the earliest possible time.

The report was accepted by the City Council, and, at the meeting of the Aldermen June 15, the following order was introduced by Alderman Welch : —

Ordered, That the care and maintenance of all sewers now in charge of the Committee on Improved Sewerage be placed in charge of the Sewer Department.

This order was laid on the table, but taken up at the meeting on July 6 and passed. In the Common Council it was laid over from time to time, and, at the meeting December 3, was referred to the next City Council, and the reference was concurred in by the Aldermen at their meeting December 7.

The following order was passed March 4 : —

Ordered, That the Committee on Improved Sewerage be authorized to sell, either by public or private sale, as said committee may deem best for the interests of the city, all the old machinery, tools, and materials that are no longer required for the use of the department; the proceeds of said sale to be credited to the appropriation for Improved Sewerage.

The following order was presented in the Board of Aldermen by the committee March 23 relating to a matter that failed of adoption by the City Council of the previous year, namely : —

Ordered, That the Committee on Improved Sewerage be authorized to purchase a parcel of land in the Calf Pasture, so called, near the pumping-station at Old Harbor Point, containing 45,709 square feet, as shown on a plan thereof in the office of the City Engineer, at the rate of five cents per square foot; the expense to be charged to the appropriation for Improved Sewerage.

The order was passed by the Aldermen March 30, and was made the subject of discussion in the Common Council (see Proceedings, p. 291) ; but after a visit by that body to the locality, April 30, they concurred with the Aldermen at a meeting on the same date, and the order received the Mayor's approval May 5. **1885.**

At the meeting of the Aldermen March 30 the following order to print the history of the works was presented by Alderman Donovan, as recommended by the Committee on Improved Sewerage, viz. : —

Ordered, That the Committee on Improved Sewerage be authorized to prepare and print a history of the Improved System of Sewerage, and that 1,500 copies be printed; the expense, not exceeding the sum of $1,500, to be charged to the appropriation for Improved Sewerage.

The order passed in the Board of Aldermen, but, being amended in the Common Council, it was indefinitely postponed upon the return to the Aldermen. A new order of the same tenor was introduced at the meeting of the Common Council April 30, and referred to the Committee on Improved Sewerage. The committee reported back favorably thereon May 7, and the order was passed by the Council on that date, concurred in by the Board May 11, and approved May 13. A subsequent order was passed Sept. 22 authorizing the Clerk of Committees to prepare and print 1,000 additional copies of the report, with this review as an appendix, and the number was increased to 1,200 by an order passed October 19.

A request was received May 11 in the Board of Aldermen, from the Committee on Improved Sewerage, for an additional appropriation of $250,000, setting forth that such sum would be required to complete the work. (See Doc. 62.)

The matter was referred to the Committee on Finance, who reported back May 25 recommending the negotiation of a loan to the amount of $200,000, and the required order was passed June 9.

The Titus claim, which has become somewhat celebrated, was introduced at the meeting of the Aldermen April 20, in the form of a petition of Lillie B. Titus and another, asking that the sewerage works at Moon Island be properly fenced, and this petition was referred to the Committee on Improved Sewerage. The committee made a report June 22, in the form of the following order: —

Ordered, That there be allowed and paid to Lillie B. Titus the sum of $15,000, upon her giving to the city a release and discharge, satisfactory to the Corporation Counsel, of all claims on account of the taking of a certain parcel of land, taken as belonging to Barnabas Davis, trustee under the will of James Huckins, consisting of land upon the main land at Squantum, so called, and of Moon Island, and the Little Moon Island, with the beach and flats around and adjoining the same, and more particularly described in paragraph 3 of City Document 92

1885. of 1879; and also a conveyance of all her right, title, and interest in said real estate; and that His Honor the Mayor be authorized to release to said Lillie B. Titus, in a manner satisfactory to the Corporation Counsel, all the interest which the city may have acquired by said taking, in Little Moon Island, and the bars and flats adjacent thereto; the real estate, island, bars, and flats referred to being shown on a plan made by William Jackson, City Engineer, dated June 15, 1885, and deposited in the office of the City Engineer; said sum to be charged to the appropriation for Improved Sewerage.

The order was tabled and the opinion of the Corporation Counsel was called for in relation to the rights of the city of Moon Island, under the order of taking, and the following opinion was received August 17, viz. (see Doc. 117): —

CORPORATION COUNSEL'S OFFICE,
2 PEMBERTON SQUARE, BOSTON, Aug. 1, 1885.

To the Honorable the Board of Aldermen: —

The order relating to Moon Island and other lands, referred to me by the Board, proposes to pay L. B. Titus $15,000, and to release to her "all the interest which the city may have acquired by said taking (of Sept. 19, 1879, City Doc. 29 of 1879) in Little Moon Island, and the bars and flats adjacent thereto," upon her giving to the city (Item 1) "a release and discharge satisfactory to the Corporation Counsel, of all claims on account of the taking of a certain parcel of land" described in the order; and (Item 2) "conveyance of all her right, title, and interest in said real estate."

Referring to Item 1, I have to report that Mrs. Titus has no legal claim against the city on account of the taking therein mentioned, and that the proposed release and discharge of all claims on account of that taking would be of no value, and should not be regarded as any consideration for the proposed payment.

That taking was made in 1879. A remedy, and the sole remedy, for damages therefor, in case the parties could not agree, was provided by the statute, and even if the city had paid no damages, all claims under that statute were long since barred. But the fact is, though not material in law, that the parties did agree, and the city did pay $25,000 to the owners, who (Mrs. Titus being one of them) executed a release to the city in which they acknowledged the receipt of said sum "in full compensation for the lands and rights aforesaid, and for all claims for damages for said taking thereof, and for building said sewer and said Improved System of Sewerage."

In regard to the second item, namely, "a conveyance of all her right, title, and interest in said real estate," I observe that the "said real estate" includes Little Moon Island; and the effect of the order, if carried out, would be to give to the city the fee of that island, and to Mrs. Titus the rights acquired therein by the city, — an exchange of interests which would be of no benefit to either party.

With reference to Moon Island, I find that Mrs. Titus derives her title from the will of James Huckins, through a deed from Barnabas Davis, trustee, which recites that the estate conveyed is "subject to the easement and rights of the City of Boston, taken in the same for the purpose of maintaining a system of improved sewerage, by virtue of the Act of the Legislature of 1876, Chapter 136." This leads to the question, What are the rights of the city to which Mr. Titus' estate is thus subject? **1885.**

The claim that the city has only a right of way on Moon Island has no legal foundation. A great public work was to be undertaken, and the Legislature gave to the city the right to take such lands as might be necessary to accomplish that work. The statute made the city the sole judge of the necessity. In the exercise of its powers it has taken Moon Island, and has acquired an absolute right to make all uses of it, directly or incidentally conducive to the advancement of the public benefit contemplated by the statute. The powers of the city in this direction have not been exhausted. If the city should find it necessary to build other reservoirs, or to make other uses of the land taken, for purposes incident to the maintenance of the sewer and the discharge of the sewage, it may do so. Technically, this right is called an easement, but for all purposes for which the land was taken the easement is as good as the fee. To illustrate: It is just as large an interest as the city acquired when it took lands for the water-supply and works on the Sudbury River. The question of damages done by the taking is rarely, if ever, affected by the fact that the fee of the land is not taken. The easement is regarded as perpetual and practically exclusive. In the case of a taking of land for supplying a city with water, the Supreme Court, through Chief-Justice Chapman, has said: "In thus taking the land the company (city) may reserve to the owner such rights of way, or other rights, as they may think proper, and the record will show that they are reserved. Such reservations may diminish his claim for damages, but no rights which are not thus reserved will exist. A parol assent that he may have a right of way, or pasturage, or tillage, may be revoked by the city; and a present intent of the city to use a part of the land merely for a cart-way, expressed by mere parol, may be changed at their pleasure. If they lay their pipes upon the land they may decide how far below the surface they shall be laid, and may vary the depth as they shall think proper; and, when they have dug their ditch for the purpose, they may decide whether or not to fill it, and make the surface smooth, so that it can be used as a way. And, as they cannot now foresee what their future necessities or interests may be, it is important for them to limit their rights as little as possible. Probably it is with this view that they have omitted to make any reservation." (Ham *v.* Salem, 100 Mass., 350.)

I think that the city acquired similar rights by the taking of Moon Island, and that Mrs. Titus holds the bare fee subject to these rights.

It should be remembered that the city holds this land as the agent of the public for the public use for which it was taken, and that land so used is not liable to taxation. If the city should purchase the fee, it would not thereby acquire the right to use any part of the island for other purposes without rendering the part so used liable to taxation by the assessors of Quincy, like other real estate not exempted. When the city took Moon Island it was assessed for $4,500. In 1883 the valuation was reduced to $4,000. In 1884 the quantity of land was put down by the assessors at 20 acres, and, upon the petition of Mrs. Titus, the valuation was again reduced to $3,000.

1885. With reference to the communication from Mrs. Titus, dated July 16, 1885, I am of opinion that no action is necessary, as the city has the right to remove earth, sand, and gravel from one part of the land taken to another, for the construction of works essential to a proper and convenient discharge of the contents of the sewer.

Very respectfully,

E. P. NETTLETON,

Corporation Counsel.

In the mean time His Honor the Mayor transmitted the following notice which he had received from the petitioner, viz. : —

To the City of Boston, Hon. Hugh O'Brien, Mayor of said Boston: —

You are hereby notified that said city of Boston will be held strictly responsible by me for any and all acts of trespass and injury done by said city's servants and agents to the real estate belonging to me, and known as Moon Island, situated in the town of Quincy, County of Norfolk, and Commonwealth of Massachusetts; that I refuse to permit said Boston to use or take any earth, gravel, or soil from said Moon Island, or change the present position and location of the same, or to dig up or wash away the realty for any purpose whatever, either to fill any place or to abate any nuisance at or near said Moon Island, or at any place.

The said Boston's easement in said Moon Island does not warrant any such use of the soil. You will please take notice that I shall hold said Boston responsible for all illegal or wrongful acts of its servants and agents, and shall take such legal steps to prevent the same as I am advised are proper in the premises.

I respectfully ask and notify you to stop the trespassing upon and misusing of said property immediately, and not to use the same for purposes and in a manner not justified or warranted by said Boston's easement.

Very respectfully yours,

L. B. TITUS.

Boston, July 16, 1885.

The whole matter was discussed at length by the Aldermen at the meetings September 14 and 21 (see Proceedings, pp. 552, 556, 576, 577), and the original order was passed by the Aldermen, after being amended by inserting after the word "her," in the second line, the words "vacating and abandoning all suits already commenced."

Upon reaching the Common Council the matter was referred to the Committee on Judiciary, on certain legal questions that arose regarding the authority of the Common Council in the matter. That committee reported the following opinion of the Corporation Counsel, October 22, viz. : — **1885.**

CORPORATION COUNSEL'S OFFICE,
2 PEMBERTON SQUARE,
BOSTON, Oct. 1, 1885.

W. H. H. EMMONS, Esq., *Chairman of the Judiciary Committee* : —

DEAR SIR, — You inquire whether, in my opinion, the order to pay Lillie B. Titus $15,000 requires for its passage the concurrence of the Common Council.

I answer Yes; first, because it contemplates a settlement of claims against the city for past action of the City Council, to wit, the taking of land in 1879 for the Improved Sewerage System; and, second, because it proposes to release the city's interest in a part of the land so taken. These are questions which are clearly not within the exclusive jurisdiction of one branch of the City Council. The Statute of 1885, Chapter 249, to which reference has been made, has no bearing upon this order. That statute authorizes the Board to take land; this order looks to a settlement of claims already taken.

In last week's proceedings of the Council I am reported to have said to Mr. Fisk that I thought it would not be necessary to have the concurrence of the Council upon this order. This was either a slip of Mr. Fisk's tongue or of the reporter's pen. I have not seen Mr. Fisk in this connection, nor have I ever for a moment hesitated to say that the order would require the concurrence of the Common Council.

Very respectfully,
E. P. NETTLETON,
Corporation Counsel.

Consideration of the subject was resumed at the meeting of the Common Council November 12, and, after extended discussion, the order was passed in concurrence. (See Proceedings, pp. 718 – 723.) The order failed of approval by His Honor the Mayor, and the following veto message. stating the reasons for disapproval, was received by the Aldermen at their meeting November 16 : —

EXECUTIVE DEPARTMENT, November 16, 1885.

To the Honorable Board of Aldermen : —

GENTLEMEN, — I return to the branch in which it originated the order to pay Lillie B. Titus the sum of $15,000, and submit the following reasons for withholding my signature from the same : —

1. The taking of Moon Island by the city in 1879, under the authority of the Legislature, gave to the city the right to use it for all purposes incident to the construction and maintenance of the system of sewerage contemplated by the Statute of 1876. For all damages incident to that taking, the city, in December, 1881, paid the owners $25,000. They have made no further claim on account of

1885. that taking, and the Corporation Counsel informs me that it is not possible to maintain any further claim on that account.

The release of all claims for such taking, as provided in the order, would therefore be of no benefit to the city, and cannot be regarded as any consideration for the proposed additional payment of $15,000.

2. The "vacating and abandoning of all suits already commenced" is named in the order as another consideration for the payment of $15,000. There is, in fact, but one suit pending, an action in which damages are claimed for the removal of gravel and loam from Moon Island, and used in the construction on the works at Old Harbor Point and Calf Pastures. This claim appears to be grossly exaggerated. The City Engineer informs me that the material removed was measured, and that instead of there being "tens of thousands of squares," as stated in the course of the discussion in the Common Council, there were in fact but 623 cubic yards of gravel and 5,779 cubic yards of loam so removed; that is less than 80 squares of gravel, and less than 725 squares of loam.

The Corporation Counsel informs me that the city had the right to use this material, and that the action cannot be maintained.

But, supposing it can be maintained, the damages provable cannot exceed $1,000. When the city paid the owners $25,000, they gave a receipt for that sum and acknowledgment "in full compensation for the lands and rights aforesaid, and for all claims for damages for said takings thereof, and for building said sewer, and for said Improved System of Sewerage," and it was fully intended and understood that the city should be thereby released from every liability to suit by the owners, for any use it might make of the island in connection with its system of sewerage, at least so long as no nuisance was created. If more money is to be paid on this account the order should contain some proviso that shall protect the city from future as well as pending suits.

3. There remains, then, as the principal, if not the only consideration which the city is to receive for its payment of $15,000, "a conveyance of all her right, title, and interest in said real estate." I am unable to see how the ownership of the fee in this island can be of any value to the city. The only use the city has for the island is in connection with its Improved Sewerage System. For that use the rights which it has already acquired are ample. The Corporation Counsel says in his opinion: "In the exercise of its power it (the City) has taken Moon Island, and has acquired an absolute right to make all uses of it, directly or indirectly conducive to the advancement of the public benefit contemplated by the statute."

Moreover, if the city should purchase the fee, it would not thereby acquire the right to use any part of the island for other purposes, without rendering the part so used liable to taxation by the assessors of Quincy. And, though the valuation was put down by the assessors last year to $3,000, upon the petition of Mrs. Titus for a reduction of vāluation, I do not see how the city could hereafter object to a valuation at such larger sum as it may volunteer to pay for it. I do not think it advisable to thus expose the city to an annual tax forever upon a mere title which will be of no benefit.

4. Irrespective of other considerations, as the city is under no present necessity of acquiring the fee of the island, it seems to me a sufficient objection to the payment of so large a sum of money, that the valuation put upon it by the owner herself before the Assessors was less than $4,000.

5. There is a legal objection to the order in its present form, which has been before pointed out by the Corporation Counsel. The conveyance, which by the terms of the order Mrs. Titus is to give to the city, includes the fee of Little Moon Island. This, if carried out, would impose upon the city an additional liability to taxation, while, at the same time, by the release which the Mayor is authorized to make, it would be deprived of the right to use the island for any purpose whatever. If the order should pass in its present form, I could not with due regard to the interests of the city, exercise the authority which it proposes to confer upon the Mayor. **1885.**

Respectfully submitted,

HUGH O'BRIEN,
Mayor.

The Aldermen, however, passed the order by a unanimous vote, notwithstanding the Mayor's veto. On reaching the Common Council, November 19, the Aldermen's action was reversed, and the Mayor's veto sustained, and the order rejected. (See Proceedings, pp. 755–758.) A new order was, however, introduced at the same meeting similar in form to that which the Council had rejected, as follows: —

Ordered, That there be allowed and paid to Lillie B. Titus the sum of $15,000, upon her giving to the city a release and discharge, satisfactory to the Corporation Counsel, of all claims against said city, and a deed of certain parcels of land, taken as belonging to Barnabas Davis, trustee under the will of James Huckins, consisting of land upon the main land at Squantum, so called, and of Moon Island, with the beach and flats around and adjoining the same, and more particularly described in paragraph 3 of City Document 92 of 1879 (excepting Little Moon Island, with the flats and bars adjacent thereto), and that his Honor the Mayor be authorized to release to said Lillie B. Titus, in a manner satisfactory to the Corporation Counsel, all the interest which the city may have acquired by said taking in Little Moon Island, and the bars and flats adjacent thereto; the real estate, islands, bars, and flats referred to being shown on a plan made by William Jackson, City Engineer, dated July 15, 1885, and deposited in the office of the City Engineer; said sum to be charged to the appropriation for Improved Sewerage.

This order passed the Common Council December 10, reached the Aldermen at their meeting December 14, and was specially assigned to the next meeting, December 21, and then referred to the Committee on Finance. That committee reported, December 28, that the order ought not to pass, and the same date the following notice was received from the claimant. The report was accepted, and, together with the notice, was sent to the Common Council, viz.: —

1885. Boston, Dec. 28, 1885.

To the Honorable Board of Aldermen, City of Boston: —

Some months ago a proposition was made to me by the Committee on Improved Sewerage looking towards a settlement of my claim for payment for material taken by the city from Moon Island, and for the conveyance by me to the city of the fee in Moon Island and in other land adjacent thereto. The offer of $15,000 for an immediate settlement was made to me last May, and I signified my readiness to accept such sum. The measure was subsequently passed by both branches of the City Council, but was vetoed by the Mayor. I therefore now desire to inform you that I am no longer prepared to accept such sum in settlement of said claim and for the fee in said lands, and I hereby withdraw my offer.

LILLIE B. TITUS.

The report of the Committee on Finance was accepted by the Common Council in concurrence at the meeting December 30, and the above communication placed on file.

The following order for exchange of land in the Calf Pasture was passed June 8: —

Ordered, That the Committee on Improved Sewerage be authorized to enter into an agreement with the Bay State Gas Company for an exchange of certain small parcels of land in Calf Pasture, shown on a plan of said lands in the office of the City Engineer, for the purpose of straightening and improving the boundaries of the city's land; and that the Mayor be authorized to execute such deeds or other instruments as may be necessary to effect such exchange.

The committee were authorized, by an order passed June 8, to purchase the fuel required for the Main Drainage Works during the year.

An order was passed September 14 requesting the committee to report whether the tug-boat "William Woolley," purchased by the city, was properly equipped for the service of extinguishing fires along the water-front, and also whether said tug-boat can be available when required as an auxiliary of the Fire Department. No report was received on the subject from the committee.

By an order passed October 19 the City Architect was granted the use of the steam-tug "Nettie," during the construction of proposed new buildings on Long Island.

The following order was passed October 19, viz.: —

Ordered, That the Committee on Improved Sewerage be authorized to invite the American Society of Mechanical Engineers to visit the Main Drainage

Works, November 11, 1885; the expense incurred thereby to be charged to the Contingent Fund of Joint Committees. **1885.**

An order was presented at the meeting of the Aldermen December 14 requesting the Committee on Improved Sewerage to consider and report on the expediency of the city's taking a tract of land for the Main Drainage Works at Squantum, near the east shaft of the Dorchester-Bay tunnel. The order was referred to the committee, but was not reported on by them.

An order was passed January 4, 1886, to pay the Builders' Iron Foundry of Providence, R.I., the sum of $192.26, in settlement of their contract for furnishing pumping-machinery for the east shaft.

No other matters of importance relating to the Improved Sewerage were acted upon by the City Council, and the review ends with the close of the municipal year 1885.

1888.

APPENDIX B.

SCHEDULE OF EXPENDITURES, MAIN DRAINAGE WORKS, JAN. 1, 1888.

Section 1, Main Intercepting Sewer . . .	$39,327 79
" 2 " " " . . .	38,778 54
" 3 " " " . . .	43,037 73
" 4 " " " . . .	55,051 12
" 4½ " " " . . .	113,082 63
" 5 " " " . . .	98,854 82
" 6 " " " . . .	154,357 99
" 1, East side " " . . .	121,897 55
" 2 " " " " . . .	76,419 70
" 3 " " " " . . .	43,392 15
" 4 " " " " . . .	38,781 20
" 5 " " " " . . .	17,017 98
" 1 and 2, West side " . . .	135,100 40
" 3 " " " . . .	22,042 72
" Brimmer street " . . .	32,579 73
" 4, West side " . . .	42,230 59
" 5 " " " . . .	36,389 31
" 6 " " " . . .	37,333 91
" 1, South Boston " . . .	42,832 29
" 2 " " " . . .	47,367 98
" 3 " " " . . .	50,992 49
" 4 " " " . . .	60,037 95
" 5 " " " . . .	57,748 18
" 6 " " " . . .	16,229 65
" 1, Stony Brook	40,942 65
" 2 " "	64,039 97
" Roxbury Canal Dredging . . .	1,336 00
" 1 Outfall Sewer, Pumping-station, etc. .	1,699,333 45
" 2 " " Dorchester Bay Tunnel .	691,753 87
" 3 " " and Moon Island Reservoir,	825,659 18
Outlet Sewer Section	103,760 39
Maintenance	61,200 46
Land damages	223,016 61
Amount carried forward,	$5,123,504 14

	1888.
Amount brought forward,	$5,123,504 14
Engineering, superintendence, preliminary survey, contingencies, and miscellaneous work . .	268,903 14
Total amount for construction . . .	$5,392,407 28
Amount transferred from appropriation . . .	67,500 00
Total expenditures to January 1, 1888 . .	$5,459,907 28

1888.

LAND TAKEN BY OR RELEASED TO THE CITY ON ACCOUNT OF CONSTRUCTION OF IMPROVED SEWERAGE SYSTEM.

A strip 20 feet wide, between Clapp and Boston Streets, reserving use of surface to previous owners, area, 10,512 feet.

Hyde Street, Dorchester Avenue to O. C. R.R., reserving rights of way to previous owners, area, 44,060 feet.

Washington Avenue, Hyde Street to Locust Street, reserving rights of way to previous owners, area, 92,600 feet.

Locust Street, Washington Avenue to Von Hillern Street, reserving rights of way to previous owners, area, 6,600 feet.

Von Hillern Street, Locust Street to Mount Vernon Street, reserving rights of way to previous owners, area, 24,000 feet.

Mount Vernon Street, across O. C. R.R., area, 2,952 feet.

Extension of Mount Vernon Street, across Calf Pasture, reserving rights of way to previous owners, area, 203,050 feet.

Pumping-station lot at Old Harbor Point, area, $22\frac{1}{2}$ acres.

A strip 20 feet wide, from low water in Dorchester Bay to and across a roadway on Squantum Neck, reserving use of surface to previous owners, area, 12,155.

Upland at Squantum, area, $2\frac{3}{10}$ acres.

Upland at Moon and Little Moon Islands, area, $37\frac{65}{100}$ acres.

Flats about Moon Island and Squantum, area, 152 acres.

Right to use, conjointly with other users, a portion of roadway at Squantum, 2,045 feet long $\times$ 32 feet wide = 15 acres.

Extension of Lowland Street, South Boston, from Jenkins Street to O. C. R.R., reserving rights of way to previous owners, 475 $\times$ 40 feet = 19,000 feet.

Land for sheds and storage on E. Chester Park, east of Albany Street, 7,704 sq. feet. Set off for use of Improved Sewerage, by Committee on Lands.

45,709 sq. feet of land adjoining Pumping-station lot at Old Harbor Point.

2,950 sq. feet of land added to Pumping-station lot, by exchange with Bay State Gas Co.

APPENDIX C.

PUMPING ENGINE TESTS.

(Compiled from City Engineer's Annual Report for 1884-1885-1886-1887.)

On March 24, 25, and May 1, 2, 1885, tests were made to ascertain the duty of Engine No. 3, and the efficiency of the boiler used in connection with it. The tests were made, under the direction of the City Engineer, by members of his staff.

The engine tested is one of the high-duty engines designed by Mr. E. D. Leavitt, Jr., on general specifications prepared by Mr. J. P. Davis, when City Engineer. It was built by the Quintard Iron Works, of New York. A description of the engine and boilers has already been printed in previous reports, in the history of the Main Drainage Works, and in the Journal of the Association of Engineering Societies, and will not be repeated here. Steam was furnished by Boiler No. 2.

The intended duration of each test was twenty-four hours.

The method of making the tests was as follows: Steam was raised in the boiler until the pressure was sufficient to run the engine. The fires were then drawn, the ash-pits carefully cleaned, and new fires were started. It was desired to determine the quantity of water pumped, by actual measurement, in the reservoir at Moon Island; and since stopping the engine would have caused large fluctuations of level in the connecting sewers, and so prevented accuracy of measurement, it was decided to keep the engine running at a constant rate. This was done by furnishing the engine with steam from Boiler No. 3 until a few minutes after the new fires were started, when, by operating the valves rapidly and simultaneously, Boiler No. 3 was shut off, and the engine took steam from No. 2, thus beginning the engine test. The engine counter was read at the instant the test began, and the other necessary observations were taken. The steam pressure was increased from about 70 pounds at the start, until it reached 100 pounds, at which it was kept constant until near the end of trial, when the fires were burned as low as possible, the steam pressure dropping in consequence. When the pressure and height of water in the boiler were the same as at the beginning of the experiment, the final observations were taken, and the fires were drawn. The refuse was then spread upon the floor to cool. The unburnt coal was picked from the ashes and weighed. This weight (averaging less than one per cent. of the total coal) was deducted from the gross amount of coal charged. The valve between Boilers No. 2 and No. 3 is supposed to have been tight; but, to avoid increasing the duty by any leakage, the pressure in the latter was kept lower than in the former.

The height of the sewage in the pump-well was determined by a float-gauge, tested before each trial; the load on the pump by a mercurial gauge, attached to the force-main of another engine. This gauge represented the height in the pipe-chamber at this end of the force-mains, and, to get the actual pressure pumped against, it was necessary to add the friction in the force-main used. During the second test the actual pressure against which the pumps were working was measured by the elevation of the surface of water in a box at the top of a pipe connected with the force-main a few feet from the pump. A comparison of this gauge with the mecurial one gave a correction for friction in the force-main to use with the first test.

Dry Cumberland coal from the Pocahontas mine was used during the trial. It was fed to the boiler from a car holding about 1,200 pounds. During the first test the car and contents were reweighed at the end of each half-hour, and during the second test after each firing.

The steam pressures at the boiler and the pressures and vacuum at the engine were determined by Bourdon's gauges, which had been previously tested.

The temperature of the steam was taken by a thermometer inserted in the main steam-pipe within a few feet of the boiler. This thermometer was broken, so that readings could not be taken during the second test.

The barometer was an aneroid placed in the engine-room.

The quantity of water fed to the boiler was measured in the following manner: A barrel, holding about 150 gallons, was placed upon a tested platform-scale, and supplied with cold water from the Cochituate main, and also with condensed water from the reheaters and steam-cylinder jackets. During the second test the exhaust steam from the boiler feed-pump was condensed in a small barrel placed above the weighing-barrel, into which it was drawn from time to time.

After having been weighed the water was run into a large tub, from which the feed-pump drew its supply. The measurement of the feed-water was checked by a Worthington water-meter placed between the feed-pump and the feed-water heater.

To ascertain approximately the amount of water returned from the cylinder-jackets and reheaters, the amount of cold water used was measured during the second test by a meter placed on the Cochituate supply.

About seven hours after the beginning of the first test a small leak was discovered from a safety-valve on the boiler feed-pipe between the pump and the hot-water meter. After being discovered, the water leaking was caught and returned to the feed-pump tub. For a period of about fourteen hours the leakage was weighed, and the rate so determined was used to make a correction for the time before the leak was discovered. The total amount of this correction was 650 pounds.

On the second test all pipe-connections with feed-pipes, boilers, and engine, except those in use, were disconnected, to avoid all chance of error from leakage.

Temperatures of the feed-water were taken before and after passing through the feed-water heater by means of thermometers inserted in the feed-pipe.

A thermometer in a tube partially filled with oil was inserted in the flue to ascertain the temperature of the gases beyond the feed-water heater, and on the second test a similar thermometer was placed in the flue between the boiler and heater.

Throughout the trials half-hourly observations were made of the engine counter, pressure of steam at engine and boilers, vacuum in condenser in inches of mercury, height of water in boiler, height of water in tub holding feed-pump supply, water-meters on boiler feed-pipe and cold-water pipe, barometer, temperature of steam, temperature of gases in flue, and temperature of engine-room. Fifteen-minute readings were taken of the force-main and pump-well gauges, and readings of the feed-water thermometers every ten minutes.

Temperatures of the external air and indicator diagrams from the steam-cylinders were taken hourly.

A large number of observers were employed, and care was taken to secure accuracy in all of the observations. The more important records were also taken independently by assistants of Mr. Leavitt.

No calorimeter tests were made to ascertain the quality of the steam. For the purposes of calculation it has been assumed that all of the water was evaporated into dry steam.

RECORD OF TWO DUTY TESTS OF ENGINE NO. 3 (LEAVITT) AT THE BOSTON MAIN DRAINAGE WORKS.

	First Test.	Second Test.
1. Date of trials	Mar. 24, 25, 1885.	May 1, 2, 1885.
2. Time of beginning trial	10.06 A.M.	10.31 A.M.
3. Duration	24h. 43m.	24h. 3½m.
4. Total revolutions	19,526.	19,372.
5. Revolutions per minute	13.17.	13.42
6. Displacement of pumps per revolution	226.19 cu. ft.	226.19 cu. ft.
7. Distance from 0 of gauge down to sewage in pump-well	11.68 ft.	15.48 ft.
8. Height of sewage in pipe-chamber, as given by mercurial gauge, graduated to give equivalent height of column of fresh water	25.76 ft.	26.55 ft.
9. Pressure in force-main near the pump, as indicated by column of fresh water at temperature 55° F	....	26.95 ft.
10. Correction of mercurial gauge for friction in force-main, from data furnished by comparison of No. 8 and No .9	0.36 ft.	....
11. Total lift	37.80 ft.	42.43 ft.
12. Weight of fresh water per cubic foot	62.42 lbs.	62.40 lbs.
13. Total weight of dry coal consumed	8,307 lbs.	9,478 lbs.
14. Duty of engine as developed by the trials: —		
1st trial $\frac{19526 \times 226.19 \times 37.80 \times 62.42}{83.07} =$	125,450,000[1]	....
2d trial $\frac{19372 \times 226.19 \times 42.43 \times 62.40}{94.78} =$	....	122,400,000
15. Mean pressure of steam in boilers	99.4 lbs.	98.6 lbs.

[1] To reduce this duty on the first trial to the usual standard, it is necessary to make a correction for the coal used to supply steam to the feed pumps. Assuming the duty of the feed-pump to be 10,000,000, the corrected duty of the pumping-engine is 122,500,000.

	First Test.	Second Test.
16. Mean pressure of steam in main steam-pipe near engine.....	....	96.1 lbs.
17. Mean vacuum in condenser	28.1 ins.	28.0 ins.
18. Mean atmospheric pressure by barometer,	30.18 ins.	29.81 ins.
19. " temperature of air in engine-room.	67.5 deg.	75.2 deg.
20. " " of external air	31.7 deg.	40.6 deg.
21. Total volume of sewage pumped by plunger displacement	33,038,000 gals.	32,778,000 gals.
22. Total volume of sewage pumped. as actually measured	30,224,000 gals.	31,256,000 gals.
23. Average slip of pumps.........	8.5 per cent.[1]	4.6 per cent.
24. Indicated horse-power, as determined by the measurement of two sets of cards for each trial.................	251.5 H.P.	290.2 H.P.
25. Horse-power in sewage lifted, pump measurement, no allowance for slip..	212.9 H.P.	243.5 H.P.
26. Work done by pump in per cent. of indicated horse-power...............	84.66 per cent.	83.90 per cent.
27. Coal burned per hour per indicated horse-power........................	1.33 lbs.	1.35 lbs.

[1] At the end of the first test it was found that two of the rubber discharge-valves had been torn off, which accounts for the large slip. A study of the question indicated that this would not materially affect the duty, a view which is corroborated by the uniform relation between the indicated and the actual horse-power in the two tests. The loss of action in the pumps, when the valves were less worn, was about 2.5 per cent.

RECORD OF TWO TESTS OF BOILER NO. 2, AT THE BOSTON MAIN DRAINAGE WORKS, MADE IN CONNECTION WITH ENGINE TESTS.

Reported in the form recommended by the Committee of the American Society of Mechanical Engineers.

	First Test.	Second Test.
1. Date of trial	Mar. 24, 25, 1885.	May 1, 2, 1885.
1*a*. Time of beginning trial...............	9.58 a.m.	10.25 a.m.
2. Duration of trial	34h. 51m.	24h. 9½m.

	First Test.	Second Test.
Dimensions and Proportions.		
3. Grate surface	45.5 sq. ft.	45.5 sq. ft.
3*a*. Area of least draught	5.50 " "	5.50 " "
4. Water-heating surface	1,826. " "	1,826. " "
5. Super-heating surface	6. " "	6. " "
5*a*. Heating-surface in feed-water heater	934. " "	934. " "
6. Ratio of water-heating surface to grate surface	40-1	40-1
Average Pressures.		
7. Steam pressure in boiler by gauge	99.4 lbs.	98.6 lbs.
8. Absolute steam pressure	114.2 lbs.	113.2 lbs.
9. Atmospheric pressure by barometer	30.18 ins.	29.81 ins.
Average Temperatures.		
11. Of external air	31.7 deg.	40.6 deg.
13. Of steam	339.0 deg.	....
14. Of escaping gases before passing feed-water heater	....	439 deg.
14*a*. Of escaping gases after passing feed-water heater	183.5 deg.	194.2 deg.
15. Of feed-water before passing heater	96.5 deg.	120.7 deg.
15*a*. Of feed-water after passing heater	145.1 deg.	164.1 deg.
15*b*. Of Cochituate water	38 deg.	46 deg.
Fuel.		
18. Dry coal consumed	8,307 lbs.	9,478 lbs.
19. Total refuse dry { 1st test, 432 lbs. 2d " 497 " }	5.2 per cent.	.... 5.2 per cent.
20. Total combustible (weight of coal, item 18, less refuse, item 19)	7,875 lbs.	8,981 lbs.

	First Test.	Second Test.
21. Dry coal consumed per hour	334.3 lbs.	392.3 lbs.
22. Combustible consumed per hour	316.9 lbs.	371.8 lbs.
WATER.		
26. Total weight of water pumped into boiler and apparently evaporated... .	86,783 lbs.	98,780 lbs.
26*a*. Check on above measurement by meter measurement......................	85,640 lbs.	96,629 lbs.
26*b*. Per cent. less by meter...............	1.3 per cent.	2.2 per cent.
26*c*. Feed-water taken from Cochituate main, meter measurement...............	....	78,836 lbs.
28. Equivalent water evaporated into dry steam from and at 212° F.		
{ Including feed-water heater........	100,668 lbs.	112,113 lbs.
{ Excluding " "	96,329 lbs.	107,571 lbs.
29. Equivalent total heat derived from fuel in British thermal units.		
{ Including feed-water heater	89,993,971	100,064,140
{ Excluding " "	85,828,387	95,816,600
30. Equivalent water evaporated into dry steam from and at 212° F. per hour.		
{ Including feed-water heater.......	4,051 lbs.	4,641 lbs.
{ Excluding " "	3,876 lbs.	4,453 lbs.
ECONOMIC EVAPORATION.		
31. Water actually evaporated per pound of dry coal, from actual pressure and temperature...........	10.45 lbs.	10.42 lbs.
32. Equivalent water evaporated per pound of dry coal from and at 212° F.		
{ Including feed-water heater........	12.12 lbs.	11.83 lbs.
{ Excluding " "	11.60 lbs.	11.35 lbs.
33. Equivalent water evaporated per pound of combustible from and at 212° F.		
{ Including feed-water heater........	12.78 lbs.	12.48 lbs.
{ Excluding " "	12.23 lbs.	11.98 lbs.

	First Test.	Second Test.
Commercial Evaporation.		
34. Equivalent water evaporated per pound of dry coal, with one-sixth refuse, at 70 pounds gauge-pressure, from temperature of 100° F. = item 33 multiplied by 0.7249.		
{ Including feed-water heater.......	9.26 lbs.	9.05 lbs.
{ Excluding " "	8.87 lbs.	8.68 lbs.
Rate of Combustion.		
35. Dry coal actually burned per square foot of grate surface per hour.......	7.35 lbs.	8.62 lbs.
36. Consumption of dry coal per hour. Coal assumed with one sixth refuse. — Per sq. ft. of grade surface....	8.36 lbs.	9.80 lbs.
37. — Per sq. ft. of water-heating surface....	0.208 lbs.	0.244 lbs.
38. — Per sq. ft. of least area for draught...	69.1 lbs.	81.1 lbs.
Rate of Evaporation.		
39. Water evaporated from and at 212° F.; per sq. ft. of heating-surface per hour, excluding feed-water heater...	2.12 lbs.	2.44 lbs.
40. Water evaporated per hour, from temperature of 100° F., into steam of 70 lbs. gauge-pressure, excluding feed-water heater. — Per sq. ft. of grate surface......	74.1 lbs.	85.1 lbs.
41. — Per sq. ft. of water-heating surface	1.84 lbs.	2.12 lbs.
42. — Per sq. ft. of least area for draught....	613.0 lbs.	704.2 lbs.
Commercial Horse-power.		
43. On the basis of 30 lbs. of water per hour evaporated from temperature of 100° F. into steam of 70 lbs. gauge-pressure (= 34½ lbs. from and at 212°).		
{ Including feed-water heater.......	117 H.P.	134 H.P
{ Excluding " "	112 H.P.	129 H.P.

1885.	Engine No. 1.		Engine No. 2.		Engine No. 3.		Engine No. 4.		Total amount pumped.	Daily average amount pumped.	Daily average am't of coal used.	Per cent. of ashes and clinkers.	Quantity pumped per lb. of coal.	Average lift.	Duty in foot-lbs. per 100 lbs. of total coal.	Rainfall in city (B. W. W. pipe-yard).
	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.								
	H. M.	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*Gallons.*	*Gallons.*	*Lbs.*	*Per ct.*	*Gals.*	*Ft.*	*Ft.-lbs.*	*Ins.*
January .	37 35	40,134,054	25 22	26,038,723	523 00	674,405,820	371 19	468,925,956	1,209,504,553	39,016,276	11,837	7.2	3,295	36.6	100,962,204	4.90
February .	17 05	16,952,759	26 55	29,386,183	579 50	707,129,100	473 46	523,161,324	1,276,629,366	45,593,905	13,333	8.2	3,419	36.6	104,745,063	3.49
March . . .	5 15	5,717,483	12 15	12,584,507	239 35	306,451,656	650 55	763,207,056	1,087,960,702	35,095,506	10,700	7.4	3,283	36.6	100,466,757	1.10
April . . .	10 05	11,331,180	10 45	12,372,991	407 53	430,984,548	356 42	406,337,184	861,025,903	28,700,863	8,946	9.3	3,207	36.	96,658,963	3.53
May	8 30	9,071,512	19 40	21,629,744	576 20	646,450,596	241 38	262,341,216	939,493,068	30,306,228	9,065	9.6	3,343	35.4	99,046,904	3.75
June . . .	25 30	27,173,811	19 44	23,584,620	229 17	255,277,116	513 45	591,908,976	897,944,523	29,931,484	8,621	8.1	3,472	36.4	105,765,872	3.82
July	10 05	11,356,141	0 10	151,082	411 55	505,239,660	371 08	402,185,016	918,931,899	29,642,964	8,525	8.	3,478	37.	107,671,938	2.42
August . .	64 13	73,432,615	43 15	44,895,120	503 03	675,686,664	328 00	352,875,060	1,146,889,459	36,996,434	11,472	6.7	3,224	37.4	100,940,604	6.37
September .	8 45	9,110,925	5 55	6,369,108	373 15	416,445,192	395 01	430,913,484	862,838,709	28,761,290	8,972	7.9	3,274	36.5	99,927,981	1.60
October . .	20 40	21,703,315	22 50	23,612,208	245 22	278,824,680	594 58	651,621,348	975,761,551	31,476,179	9,641	8.1	3,265	36.2	98,910,423	5.32
November .	59 45	64,968,039	55 01	58,081,329	551 35	652,218,624	333 33	392,249,592	1,167,517,604	38,917,253	12,138	7.1	3,206	37.	99,281,135	5.86
December .	5 05	6,898,553	0 10	165,534	313 11	380,277,000	529 42	632,381,616	1,019,722,703	32,894,281	10,315	7.1	3,188	35.4	94,477,413	2.33
Totals and averages	272 33	297,850,407	242 02	258,871,149	4,954 16	5,929,390,656	5,160 27	5,878,107,828	12,364,220,040	33,874,575	10,265	7.9	3,301	36.4	100,528,650	44.49

Note.—The volume pumped is estimated by pump-measurement; the quantity of coal burned, by the firemen's returns. These should be accurate, but they fall about four per cent. short of the amount of coal weighed into the bins. The shortage of different lots has been about the same. The duty is estimated without making any deduction for ashes or for the fuel used for heating the buildings, lifting filth-cages, moving gates, etc.

1886.	Engine No. 1.		Engine No. 2.		Engine No. 3.		Engine No. 4.		Total amount pumped.	Daily average amount pumped.	Daily average amount of coal used.	Per cent. of ashes and clinkers.	Quantity pumped per lb. of coal.	Average lift.	Duty in ft.-lbs. per 100 lbs. of total coal.	Rainfall in city (B.W.W. pipe-yard).
	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.	Pumping time.	Amount pumped.								
	H. M.	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*Gallons.*	*Gallons.*	*Lbs.*	*Per ct.*	*Gals.*	*Ft.*	*Ft.-lbs.*	*Ins.*
January . .	35 20	38,511,560	55 10	59,244,008	258 26	314,339,760	698 08	860,882,832	1,272,978,160	41,063,812	12,092	6.6	3,183	34.50	91,895,636	4.96
February . .	138 15	152,651,030	136 05	149,018,483	514 59	620,547,768	643 55	774,936,000	1,697,153,281	60,612,617	19,763	6.1	3,067	35.27	90,524,726	6.17
March . . .	14 40	14,913,803	7 50	8,557,833	349 11	421,368,912	655 19	788,174,208	1,233,014,756	39,774,669	13,217	6.2	3,009	35.20	88,652,281	2.61
April	32 25	37,331,804	16 15	18,418,915	185 30	222,802,560	676 20	823,205,376	1,101,758,655	36,725,288	12,760	8.8	2,878	35.40	85,269,038	1.37
May	43 15	49,983,313	29 55	39,686,062	735 30	907,209,792	. . . .	. . . . . .	996,879,167	32,157,392	9,941	9.1	3,235	35.30	95,565,034	2.43
June	4 23	5,182,783	6 50	8,229,393	304 17	306,433,044	417 10	478,907,064	798,752,284	26,625,076	8,096	9.2	3,289	35.10	96,605,319	1.15
July	6 42	7,476,608	2 35	3,217,398	356 20	598,668,516	320 44	374,691,708	984,054,230	31,743,685	9,609	11.6	3,303	35.10	97,042,020	1.16
August . .	17 11	19,396,353	16 37	17,909,176	545 15	652,795,596	266 59	312,018,336	1,002,119,461	32,326,434	9,414	11.0	3,433	35.70	102,594,809	2.75
September .	8 25	9,100,416	7 45	8,622,207	595 00	729,011,736	200 20	240,377,364	987,111,723	32,903,724	9,048	11.4	3,636	35.40	107,738,094	3.09
October . . .	18 05	18,518,761	25 45	28,002,794	446 55	555,146,892	368 25	433,595,304	1,035,263,751	33,395,604	9,237	10.6	3,615	35.52	107,474,364	3.10
November .	17 05	20,800,762	13 42	14,404,065	278 46	342,795,816	551 15	646,924,356	1,024,924,999	34,170,833	9,442	11.0	3,619	35.36	107,076,126	3.73
December . .	25 55	22,944,818	22 20	16,586,220	645 48	824,616,504	341 30	403,579,224	1,267,726,766	40,894,411	11,654	10.0	3,509	34.55	101,463,669	4.42
Totals and averages	361 41	396,812,011	340 49	371,896,554	5,215 57	6,495,736,896	5,140 05	6,137,291,772	13,401,737,233	36,866,129	11,259	9.3	3,315	35.20	97,658,426	36.94

NOTE. — The volume pumped is estimated by pump-measurement; the quantity of coal burned, by the firemen's returns. The duty is estimated without making any deduction for ashes or for the fuel used for heating the buildings, lifting filth-cages, moving gates, etc.

MAIN DRAINAGE PUMPING-STATION.

Report of Pumping done during the year 1887.

1887.	Engine No. 1. Pumping time.	Engine No. 1. Amount pumped.	Engine No. 2. Pumping time.	Engine No. 2. Amount pumped.	Engine No. 3. Pumping time.	Engine No. 3. Amount pumped.	Engine No. 4. Pumping time.	Engine No. 4. Amount pumped.	Total amount pumped.	Daily average amount pumped.	Daily average amount of coal used.	Per cent. of ashes and clinkers.	Gallons pumped per lb. of coal.	Average lift.	Duty in ft.-lbs. per 100 lbs. coal.	Rainfall.
	H. M.	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*H. M.*	*Gallons.*	*Gallons.*	*Gallons.*	*Lbs.*	*Per ct.*	*Gals.*	*Ft.*	*Ft.-lbs.*	*Ins.*
January . .	147 05	166,325,957	98 05	113,162,031	560 42	666,277,452	724 42	872,335,980	1,818,101,420	58,648,433	18,030	10.3	3,253	34.45	93,782,861	6.01
February . .	39 47	44,152,846	71 22	82,086,352	618 00	771,470,784	504 50	609,468,552	1,507,178,534	53,827,805	15,196	10.1	3,542	34.20	101,385,783	4.43
March . . .	78 48	93,927,271	38 05	44,922,709	685 32	848,333,268	537 54	651,408,156	1,638,591,404	52,857,787	14,913	10.6	3,544	33.95	100,706,454	4.69
April	38 20	41,958,868	35 35	41,216,592	536 58	647,902,332	654 10	781,868,124	1,512,945,916	50,431,531	13,894	12.2	3,630	34.60	105,105,278	3.48
May	6 15	7,018,106	8 20	9,812,473	281 13	341,826,300	620 53	763,998,912	1,122,655,791	36,214,703	10,460	17.4	3,462	34.65	100,399,153	2.14
June	4 30	5,277,374	23 30	27,544,292	706 03	905,710,680	233 25	280,398,240	1,218,930,586	40,631,019	11,687	11.4	3,476	34.50	100,388,683	2.03
July	19 50	23,363,908	24 43	27,495,682	339 57	417,480,696	589 14	715,001,976	1,183,342,262	38,172,331	11,326	12.3	3,370	34.88	98,383,477	4.26
August . . .	24 23	29,128,686	37 25	45,605,865	414 02	522,235,800	506 31	608,351,832	1,205,322,183	38,881,361	11,768	11.4	3,304	34.69	95,921,655	3.38
September .	3 30	4,285,485	30	568,858	341 50	422,673,444	531 05	645,800,868	1,073,328,655	35,777,621	10,303	11.1	3,472	34.70	100,844,171	1.24
October . . .	17 50	21,758,493	16 13	19,462,041	471 07	595,540,008	425 21	520,472,736	1,157,233,278	37,330,106	10,603	11.4	3,520	34.40	101,359,036	2.58
November .	15 50	19,112,580	20 51	25,195,290	516 49	651,902,220	347 00	417,827,556	1,114,037,646	37,134,588	10,684	11.7	3,476	34.80	101,227,274	2.14
December . .	29 35	35,359,851	35 30	43,118,917	671 20	849,441,528	361 25	425,558,304	1,353,478,600	43,660,600	13,261	10.8	3,285	34.56	95,227,136	3.02
Totals and Averages	425 43	491,669,425	410 09	480,191,102	6,143 33	7,640,794,512	6,036 30	7,292,491,236	15,905,146,275	43,630,657	12,677	11.7	3,444	34.53	99,560,914	39.40

The average daily amount of sewage pumped since the works were in operation is shown as follows :—

Date.	Daily average of sewage pumped, in gallons.			
	1884.	1885.	1886.	1887.
January	. . . . .	39,016,276	41,063,812	68,648,343
February	25,777,360	45,593,905	60,612,617	53,827,805
March	32,437,379	35,095,506	39,774,669	52,857,787
April	29,949,356	28,700,863	36,725,288	50,431,531
May	25,121,056	30,306,228	32,157,392	36,214,703
June	26,712,298	29,931,484	26,625,076	40,631,019
July	25,900,400	29,642,964	31,743,685	38,172,331
August	31,674,621	36,996,434	32,326,434	38,881,361
September	28,412,431	28,761,290	32,903,724	35,777,621
October	27,601,557	31,476,179	33,395,604	37,330,106
November	27,501,283	38,917,253	34,170,833	37,134,588
December	30,883,501	32,894,281	40,894,411	43,660,600
Average	28,379,040	33,874,575	36,866,129	43,630,657

TABULAR STATEMENT OF IMPROVED SEWERAGE CONSTRUCTION.

Section.	Locality.	Size in feet and inches.	Length in feet, Jan. 1, 1888.	Built by
1. Main	In Camden st., from Huntington ave. to Tremont st.	7 ft. 8 in.	1575.5	P. J. Condon.
2. Main	In Camden st., from Tremont st. to Washington st.	8 ft. 5 in.	1390.5	P. J. Condon.
3. Main	In Washington st. and E. Chester park, from Camden st. to Albany st.	8 ft. 5 in. × 5 ft. 8 in.	1856.5	John Cavanagh.
4. Main	In E. Chester park extension, from Albany st. to Magazine st.	9 ft.	2505.	Charles Linehan and City.
4½. Main	In E. Chester park extension, from Magazine st. to Clapp st.	9 ft.	1894.5	City.
5. Main	In Clapp and Mt. Vernon sts., from E. Chester park to O.C. R.R.	9 ft. 10 ft. 6 in.	3381.	Hoblitzell, Condon, and Hoblitzell and City.
6. Main	In Mt. Vernon st. extension, from O.C. R.R. to Old Harbor Point	10 ft. 6 in.	4088.	Clinton Beckwith and J. V. Quackenbush.
1. West Side	In Camden, Falmouth, Dalton, and Hereford sts., from Huntington ave. to Beacon st.	5 ft. 9 in. × 5 ft. 6 in.	4282.	City.
2. West Side	In Beacon st., from Hereford st. to Charles st.	4 ft. 9 in. × 5 ft. 6 in. 4 ft. × 4 ft. 6 in.	5043.	City.
3. West Side	In Charles st., from Beacon st. to Cambridge st.	4 ft. × 4 ft. 6 in.	1832.	Thomas McCann.
4. West Side	In Charles st., from Cambridge st. to Leverett st.	3 ft. × 4 ft. 6 in.	2186.	City.
Brimmer street	In Charles, Pinckney, and Brimmer sts., from Beacon st. to Revere st.	2 ft. × 3 ft. 3 ft. × 4 ft. 6 in.	1456.5	City.
5. West Side	In Brighton, Leverett, and Lowell sts., from Charles st. to Causeway st.	2 ft. 8 in. × 4 ft. 6 in. 3 ft. × 4 ft. 6 in.	1775.	City.
6. West Side	In Causeway st., from Lowell st. to Prince st.	2 ft. 8 in. × 5 ft.	1796.	City.
Friend-street Sewer	In Friend st., from Traverse to Causeway st.	15 in. pipe	492.	City.
1. East Side	In Albany st., from E. Chester park to Dover st.	5 ft. 8 in.	4524.	A. H. Delameter & Co. and R. A. Malone.
2. East Side	In Albany st., Lehigh st., and O.C. R.R. freight-yard to Federal st.	5 ft. × 4 ft. 5 ft. × 3 ft.	2331.5	City.
3. East Side	In Federal st., from O.C. R.R. freight-yard to Summer st.	2 ft. 8 in. × 4 ft. 6 in.	2176.	City.
	Carried forward		44,584.6	

TABULAR STATEMENT OF IMPROVED SEWERAGE CONSTRUCTION. — Concluded.

Section.	Locality.	Size in feet and inches.	Length in feet, Jan. 1, 1888.	Built by
	Brought forward		44,584.6	
4. East Side	In Atlantic ave., from Summer st. to Central st.	2 ft. 8 in. × 4 ft. 6 in.	2983.	City.
1. Stony Brook	In Tremont and Cabot sts., from Camden st. to Ruggles st.	4 ft. 8 in.	2135.	Myles Tierney.
2. Stony Brook	In Cabot, Hampshire, Elmwood, Ruggles, and Tremont sts., about Stony Brook	4 ft. × 4 ft. 6 in. 5 ft. × 4 ft. 6 in. 2 ft. × 3 ft. 15 in. pipe	4229.	City.
1. South Boston	In Ninth st., from H st. to N st.	3 ft. 2 in.	2717.	Stephen Connolly & Son and City.
2. South Boston	In Lowland, Burnham, and Ninth sts., from Hyde st. to H st.	3 ft. × 4 ft. 6 in.	3374.5	City.
3. South Boston	In Von Hillern st., Locust st., Washington ave., and Hyde st., from Mt. Vernon st. to Dorchester ave.	6 ft. 4 ft. 9 in. × 5 ft. 6 in. 4 ft. 6 in. × 3 ft	3739.	Charles Linehan.
4. South Boston	In Dorchester ave., from Hyde st. to B st.	4 ft. 9 in. × 5 ft. 6 in.	3352.	Hoblitzell, Condon, and Hoblitzell and City.
5. South Boston	In Dorchester ave. and Foundry st., from B st. to First st.	3 ft. × 5 ft.	2810.	City.
6. South Boston	In N. and E. Eighth, O and E. Sixth sts.	2 ft. × 3 ft. 15 in. pipe	2544.	Putterill & Killian.
Roxbury Canal	In Albany st. and E. Chester park, from Northampton st. to Roxbury Canal	4 ft. 9 in. 6 ft.	620.	City.
E. Chester Park	In E. Chester park, from Albany st. to Harrison ave.	4 ft. 6 in.	734.	City.
Dover Street	In Dover st., from Albany st. to Harrison ave.	2 ft. × 3 ft.	588.	City.
Sundry City Sewers rebuilt			2245.	City.
Pumping-Station	Connecting Main Sewer and Filth-Hoist, and Engine-Wells and Salt-Water Conduit	10 ft. 6 in. 9 ft. 5 ft. 6 in.	640.	City.
1. Outfall Sewer	From Pumping-Station to Dorchester Bay Tunnel	8 ft. × 16 ft.	2518.	City.

2. Ontfall Sewer	Tunnel under Dorchester Bay	7 ft. 6 in.	7160.	R. A. Malone.
3. Outfall Sewer	Squantum Neck to Moon Island: Brick Sewers, 1,938 ft.; Wooden Flume, 4,196 ft.; Discharge Sewers, 1,003 ft.	11 ft. × 12 ft.; 6 ft. × 6 ft.; 8 ft. 6 in. × 8 ft. and 8 ft. 6 in. × 12 ft.	7137.	W. C. Poland & Son and C. W. Parker & Co.
Outlet Sewer	From Reservoir to Outlet	10 ft. 10 in. × 12 ft.	1177.	Boynton Bros.
	Totals		95387.5	

APPENDIX D.

LIST OF OFFICERS CONNECTED WITH BOSTON MAIN DRAINAGE WORKS.

Commission of 1875.

E. S. Chesbrough, C.E.
Moses Lane, C.E.
C. F. Folsom, M.D.

Engineers.

City Engineers.

Joseph P. Davis	1876–1880
Henry M. Wightman	1880–1885
William Jackson	1885–1888

Principal Assistants to City Engineer.

Henry M. Wightman	1876–1880
Alphonse Fteley	1880–1884
John E. Cheney	1885–1888

Consulting Engineer.

Eliot C. Clarke	1886–1887

Principal Assistants in charge of Main Drainage Works.

Eliot C. Clarke	1876–1885
Fred P. Stearns	July, 1885–Aug., 1886
Seth Perkins	Aug., 1886–April, 1887
George S. Rice	April, 1887–July, 1887
Henry W. Sanborn	July, 1887–Jan., 1888

Assistant Engineers.

William Jackson	1876–1885
Fred P. Stearns	1880–1885
Clemens Herschel	1878–1880
George S. Rice	1877–1880
John E. Cheney	1879–1885
George H. Crafts	1877–1881
Seth Perkins	1877–1885
Charles S. Gowen	1880–1881
E. R. Howe	1877–1880
F. A. May	1876–1880
F. W. Ring	1876–1877
R. Tappan	1876–1877
E. O. Kimball	1885–1888

Principal Superintendents of Construction.

Sewer Construction.

H. A. Carson.

Pumping-Station.

S. H. Tarbell.

Joint Special Committee on Improved Sewerage.

1876.

Aldermen.	*Councilmen.*
Alvah A. Burrage, Chairman.	Eugene H. Sampson.
Solomon B. Stebbins.	J. Homer Pierce.
Thomas J. Whidden.	Warren K. Blodgett.
	Marcellus Day.
	Albert H. Taylor.

1877.

Aldermen.	*Councilmen.*
Choate Burnham, Chairman.	Eugene H. Sampson.
Charles W. Wilder.	J. Homer Pierce.
Lucius Slade.	Warren R. Blodgett.
	Martin L. Ham.
	George L. Thorndike.

1878.

Aldermen.	*Councilmen.*
Thomas J. Whidden, Chairman.	Eugene H. Sampson.
Solomon B. Stebbins.	George L. Thorndike.
Lucius Slade.	J. Homer Pierce.
	Frederick B. Day.
	James B. Richardson.

1879.

Aldermen.	*Councilmen.*
Lucius Slade, Chairman.	Isaac Rosnosky.
Solomon B. Stebbins.	Thomas J. Denney.
Daniel D. Kelly.	John P. Brawley.
	Daniel J. Sweeney.
	Oscar B. Mowry.

1880.

Aldermen.

Lucius Slade, Chairman.
Asa H. Caton.
George L. Thorndike.

Councilmen.

Daniel J. Sweeney.
Charles H. Plimpton.
Howard Clapp.
Malcolm S. Greenough.
Benjamin S. Brintnall.

1881.

Aldermen.

Lucius Slade, Chairman.
William Woolley.
Charles H. Hersey.

Councilmen.

Howard Clapp.
Thomas J. Denney.
Malcolm S. Greenough.
Frank E. Farwell.
John E. Bowker.

1882.

Aldermen.

Lucius Slade, Chairman.
William Woolley.
Charles H. Hersey.

Councilmen.

Malcolm S. Greenough.
Thomas J. Denney.
Frank E. Farwell.
Prentiss Cummings.
Nathan G. Smith.

1883.

Aldermen.

Lucius Slade, Chairman.
William Woolley.
Thomas H. Devlin.

Councilmen.

Malcolm S. Greenough.
Thomas J. Denney.
Frank E. Farwell.
John B. Fitzpatrick.
Patrick J. Donovan.

1884.

Aldermen.

Lucius Slade, Chairman.
Charles H. Hersey.
Malcolm S. Greenough.

Councilmen.

Thomas J. Denney.
Patrick J. Donovan.
Isaac Rosnosky.
J. Edward Lappen.
James B. Graham.

1885.

Aldermen.	*Councilmen.*
Patrick J. Donovan, Chairman.	Edward P. Fisk.
George Curtis.	J. Edward Lappen.
William J. Welch.	John Gallagher.
	William H. Murphy.
	Benjamin B. Jenks.

1886.

Aldermen.	*Councilmen.*
Patrick J. Donovan, Chairman.	D. Foster Farrar.
Nathan G. Smith.	William A. Foss.
Samuel J. Capen.	John Gallagher.
	George N. Fisher, Jr.
	Thomas J. Denney.

1887.

Aldermen.	*Councilmen.*
Patrick J. Donovan, Chairman.	William A. Foss.
Nathan G. Smith.	Henry S. Dewey.
Samuel J. Capen.	John Gallagher.
	S. Edward Shaw.
	William J. Mahoney.